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National Aeronautics and Space Administration

SPACE STATION CAPITAL DEVELOPMENT PLAN FISCAL YEAR 1989

Submitted to the

COMMITTEE ON SCIENCE, SPACE AND TECHNOLOGY
U.S. HOUSE OF REPRESENTATIVES

and the
COMMITTEE ON COMMERCE, SCIENCE AND TRANSPORTATION
U.S. SENATE

Office of Space Station
National Aeronautics and Space Administration

APRIL 1988

CAPITAL DEVELOPMENT PLAN

Capital Development Plan - FY 1989

Introduction

The "Capital Development Plan - FY 1989" is submitted in response to a directive from Congress found in the Fiscal Year 1988 NASA Authorization Act (P.L. 100-147). In accordance with Section 107 of the Act, the Capital Development Plan for Fiscal Year 1989 includes a statement outlining the projected total cost, schedule, and configuration of Space Station as well as an analysis of "The Report of the Committee on the Space Station of the National Research Council." The latter contains a discussion of the alternative configurations presented to the Committee. The Act requires the Capital Development Plan to be prepared for each of the fiscal years 1989 through 1996, and to be submitted along with the President's annual NASA budget request.

The President's National Space Policy affirms the national commitment to a permanently manned Space Station. The Space Station is essential if the United States is to maintain preeminence in key areas of civil space activities during the 1990's and beyond. The Station will stimulate the development of new technologies, advance scientific research, and help realize the commercial potential of space. Moreover, as a symbol of American technological prowess and competitive spirit, the Space Station directly supports our national goals in space. A permanently manned orbital complex is vital to America's leadership in human space flight.

The Space Station development program is making great strides toward fulfillment of the President's directive to develop a permanently manned Space Station within a decade. The configuration has been thoroughly reviewed, and the prime contractor teams chosen for Phase C/D, hardware development and advanced design. Key support contracts are in place and work has begun. A strategy to develop a Space Station Flight Telerobotic Servicer is also in place. An operations concept has been defined and baselined. User requirements are being factored into Space Station design. International negotiations with the European Space Agency, Japan and Canada are nearing completion. Thus, the Space Station has realized significant progress as it enters Phase C/D.

The Space Station Capital Development Plan for FY 1989

I. Total Space Station Development Costs

A. Introduction

A preliminary projection of the funding requirements by fiscal year from FY 1987 through FY 1993 for the Space Station Program is provided in Figure 1. Projected totals for the program are provided below. The fiscal year projections beyond FY 1989 are likely to be revised following completion of a program cost and schedule reassessment. This reassessment is being undertaken in accordance with the recommendations of the National Research Council's Committee on Space Station's report of September 10, 1987. It is being accomplished with the full support and involvement of our Space Station contractors

The data presented in Figure 1 for FY 1988 are consistent with the Omnibus Continuing Resolution of Fiscal Year 1988. This resolution provides the Space Station Program with $325 million of FY 1988 New Obligational Authority (NOA), plus $100 million to be transferred from the Space Shuttle replacement Orbiter program. Of the $425 million provided for FY 1988, $225 million of NOA will be withheld from NASA until June 1, 1988. Additionally, for FY 1988, approximately $33 million has been transferred from the Research and Development account to the Research and Program Management account, in order to comply with requirements stated in the report accompanying the FY 1987 Housing and Urban Development--Independent Agencies Appropriations Act.

For FY 1990-1993, the preliminary estimates are stated in constant FY 1989 dollars, without provision for future year wage and price escalation. The estimates do not include provision for program scope beyond that presently approved.

Most of the funds for the Space Station Program are included in the Research and Development account: one of four accounts that together comprise the NASA budget. The other accounts are Space Flight, Control and Data Communications; Construction of Facilities; and Research and Program Management. The account structure is functional in character. It provides funding data for what NASA does. The agency conducts research, undertakes development, and operates spacecraft. The first two accounts cover these activities. The next two accounts are enabling in character. Construction of Facilities covers the building of buildings and is traditionally identified separately in budgets. Research and Program management covers the NASA institution, providing funds for personnel and associated administrative tasks in support of research, development and spacecraft operations. Underlying this account is the assumption that activities in space are an ongoing activity of the United States Government, not dependent upon any single space project.

B. Space Station

The budget line item within the Research and Development account for the Space Station program consists of: definition and technology development activities;

Figure 1

National Aeronautics and Space Administration
Preliminary FY 1989 Budget Estimates
CAPITAL DEVELOPMENT PLAN FOR SPACE STATION PROGRAM
in Millions of FY 1989 Dollars

	FY 87	FY 88	FY 89	FY 90	FY 91	FY 92	FY 93
RESEARCH AND DEVELOPMENT	420	399	987	2029	2612	2929	2664
SPACE STATION	420	392	967	2003	2565	2872	2593
Definition	250	0					
Design & Development	147	367	935	1936	2495	2793	2520
Flight Telerobotic Servicer	20	21	20	43	41	43	37
Transition Definition	0	4	12	24	29	36	36
Assured Crew Returned Capability (ACRC)	3	0					
SPACE TRANSPORTATION CAP DEV	0	7	20	26	47	57	71
SPACE FLIGHT, CONTROL AND DATA COMMUNICATIONS	3	5	11	33	74	90	118
SPACE TRANSPORTATION OPERATIONS					0	6	40
SPACE & GROUND NETWORK, COMMUNICATIONS & DATA SYSTEMS	3	5	11	33	74	84	78
CONSTRUCTION OF FACILITIES	17	2	30	91	25	43	4
RESEARCH AND PROGRAM MANAGEMENT	80	95	98	101	104	107	110
TOTAL SPACE STATION	$520	$501	$1,126	$2,254	$2,815	$3,169	$2,896
(Non-Add Space Station Operations)				($24)	($72)	($171)	($447)

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design and development of the baseline Space Station; the Flight Telerobotic Servicer's definition, design and development; "transition definition"; operations; and, for FY 1987 only, the concept definition studies for a Crew Emergency Return Vehicle.

In testimony before the Congress last year, NASA presented its cost estimate for the design and development of the Revised Baseline Program, based on a First Element Launch in March 1994. This estimate was 12.2 billion in 1984 dollars, which is equivalent to 14.6 billion in 1988 dollars and 15.3 billion in 1989 dollars. This estimate of the design and development costs has not been revised for this Capital Development Plan, because the estimate is under review. However, the stretchout of the development schedule due to reductions taken in the previously planned funding through FY 1989 will require sustaining base support over a longer period. This is likely to raise the total cost of the Space Station.

Development costs refer to those funds required for the design, fabrication and testing of the Station itself. Development costs do not include those costs to be incurred for Station operations, payload/experiments or transportation to and from the Station.

In other research and development accounts of the Space Station are the program's Flight Telerobotic Servicer (through 1993, $225 million), "transition definition" ($141 million through 1993) which is the planning necessary to evolve smoothly from Space Station development/assembly to steady-state operations, and a Crew Emergency Return Vehicle (CERV) study ($3 million). In addition, the FY 1987 funds utilized by NASA to define the Space Station concept ($250 million) are separately identified. Definition funding concluded in Fiscal Year 1987. NASA believes the funds so utilized constituted a sound investment, contributing significantly to the strong design of the Space Station. With these funds, the total research and development cost of the Station is $12.0 billion through 1993. This estimate does not include the program stretchout cost. Further, the revised estimates expected later this year will reflect contractor inputs as well as private sector initiatives. Since this is a capital development plan, the preliminary funding requirements for Space Station operations are shown parenthetically for information only.

C. Space Transportation Capability Development

The Space Transportation Capability Development line in the Research and Development account in Figure 1 amounts to $228 million provides for assessments by NASA through the Office of Space Flight of possible Station transportation options and the development of new and improved capabilities needed for Station assembly and operations. These capabilities include the Space Shuttle-Station docking system, the upgrade to the Shuttle's remote manipulator system, and Space Station crew transportation. Follow-on study funds planned for FY 1988-1990 for CERV are also found in this Space Transportation line. Estimated funding necessary to design, fabricate and test such a transportation vehicle are not included. No decision on whether a vehicle is required or, if so, what kind of vehicle it should be, has been made. Also not included in this section of the Research and Development account are the estimated funding requirements for transporting the Station elements into orbit and assembling them. These estimates are found in "Space Transportation Operations," a separate section which is discussed next.

D. Space Transportation Operations

Estimated Space Shuttle transportation costs through FY 1996 for Station launch and assembly are displayed in the Space Transportation Operations section of the Space Flight, Control and Data Communications account. The assembly phase of the manned base of the Space Station will require 19 Space Shuttle flights. Of these 19 flights, 13 are to carry aloft and assemble Station elements. Four flights are for logistics. Two flights are for outfitting the laboratory and habitation modules. The U.S. polar platform could be launched by a Titan IV class unmanned launch vehicle. The overall transportation costs are estimated to be $740 million through FY 1996, based upon a marginal cost per flight of $46 million (FY 1989 dollars). The estimate also includes the potential use of a Titan IV, priced at $148 million (in 1989 dollars). (The total transportation cost through assembly completion in FY 1998 is $1,022 million.) The European Space Agency is expected to launch its polar platform with an Ariane booster. The cost estimate depicted here is associated only with the 20 U.S. launches. Potential offsets to direct funding requirements through the receipt of reimbursements for the Shuttle launch of the ESA and Japanese modules have not been incorporated into these estimates. As indicated, the Shuttle cost per flight is calculated using a marginal cost estimating approach.

It should be noted that the President's budget request for FY 1989 includes funds to develop an Advanced Solid Rocket Motor (ASRM) for the Space Shuttle. These funds are not shown in Figure 1, as they are not associated with the Space Station Program. Performance increases to the Shuttle from the ASRM could affect transportation to the Space Station, however. Greater mass per flight could be carried aloft. Margins could be increased, and the number of Shuttle fights required for Station assembly could be reduced from 19 to 14, based on recently completed analyses. Were the latter to occur, the total for transportation costs would be reduced accordingly.

E. Space and Ground Network, Communications and Data Systems

Operation of the Space Station will require considerable tracking and data acquisition capabilities. One of the significant technical advancements of the Space Station comes in the field of data generation and management. These capabilities are the responsibility of the NASA Office of Space Operations. Funding requirements are shown in the Space and Ground Network, Communications and Data Systems section of the Space Flight, Control and Data Communications account. The funds will be used for the Space Station elements of the Customer Data Operations System (CDOS), which will provide data capture, processing, and polar platform control capabilities for the Space Station. CDOS will also provide tracking, data acquisition and communications, the latter through the Tracking and Data Relay Satellite (TDRS) system. Through FY 1993, the estimated funding requirement is $288 million.

F. Construction of Facilities

Many NASA flight projects require new, unique, or modified facilities for their development and/or operation. The Space Station is no exception, although the facilities requirement for the Space Station Program is relatively modest for a program of its size and duration. NASA will use many existing facilities for the Space Station endeavor. The estimated funding currently projected for new or modifications to the existing physical plant total $212 million through FY 1993 is in constant FY 1989 dollars. Areas where new buildings are required for the Space

Station activity include pre-launch processing, logistics, training and simulations, and human performance tests.

G. Research and Program Management

The NASA R&PM line consists of the direct salaries and benefits for civil servant personnel that support the Space Station program. The overall staffing requirements for the Space Station are currently under review. The estimates in Table 1 do not provide for increasing the level of personnel above the FY 1988 level. Through FY 1993, the total cost for R&PM is $695 million.

II. Overall Space Station Program Schedule and Program Milestones

The Space Station schedule includes programmatic and internal management milestones. Programmatic milestones reflect the time periods during which major technical events important to the program should take place. Management milestones focus primarily on cost and budget reviews as well as top-level program reviews and other management oversight activities. Establishment and completion of both kinds of milestones are essential to the successful development and operation of the Space Station.

The Space Station schedule, like any other, reflects the available funding projections. The budget reductions, necessitated by the Bipartisan Summit Agreement, caused a slip in the schedule as system development is stretched out to reduce near term outlays. The schedule indicated in Figures 2 and 2A is consistent with the budget provided in the FY 1988 Omnibus Continuing Resolution, and reflects the adjustments necessitated by the Congressional reductions to the FY 1988 budget request for the Space Station and the President's FY 1989 budget.

Preliminary assessment of the impact of the budget reduction resulted in a planned slip in the programmatic schedule of approximately one year for key milestones. If a decision is made to delay some parts of the program while holding others at their original dates, the schedule will again change. NASA is examining whether it is fiscally or technically possible to maintain the schedule for development of those systems necessary for a man-tended capability, while extending the schedule for the rest of the systems needed for permanently manned capability. Although limited in capability, the Station in a man-tended phase will enable certain kinds of early research to be done.

The impact of the FY 1988 budget reduction is still being examined by the NASA centers and major contractors; thus, the milestones dates, independent of policy decisions, may change. Also, with a Shuttle equipped with an Advanced Solid Rocket Motor (ASRM) for assembly, the schedule slip might be shortened because less flights would be needed to assemble the Station.

Two of three key programmatic milestones will be delayed, although somewhat less than the hardware launch dates. The Program Requirements Review (PRR), scheduled to begin in April 1988, will remain on schedule and will be completed in July. The Preliminary Design Review (PDR) and the Critical Design Review (CDR) will slip six to nine months. All three of these reviews are critical to a well-designed, integrated Space Station. PRR will verify the requirements for the program and enable the detailed design and development process to begin. The PRR process will assure complete and consistent specification of the program, and the achievability of the requirements within the available technical and fiscal resources. The PDR, scheduled to occur in mid-1989, will then provide an early review and assessment of the Space Station system design, of Station elements, system, subsystem, and lower level designs to assure that the overall design satisfies requirements. The CDR will be a final critical review of the detailed design and test plans of all ground and flight aspects of the Space Station program. CDR will begin in mid-1991.

The preliminary revised Space Station schedule establishes the First Element Launch (FEL) in early calendar year 1995, man-tended capability in the last quarter of calendar year 1995, and a permanently manned capability in the last quarter of 1996. Launch of the polar platform is still scheduled for late 1995.

Figure 2
SPACE STATION PROGRAM MILESTONES

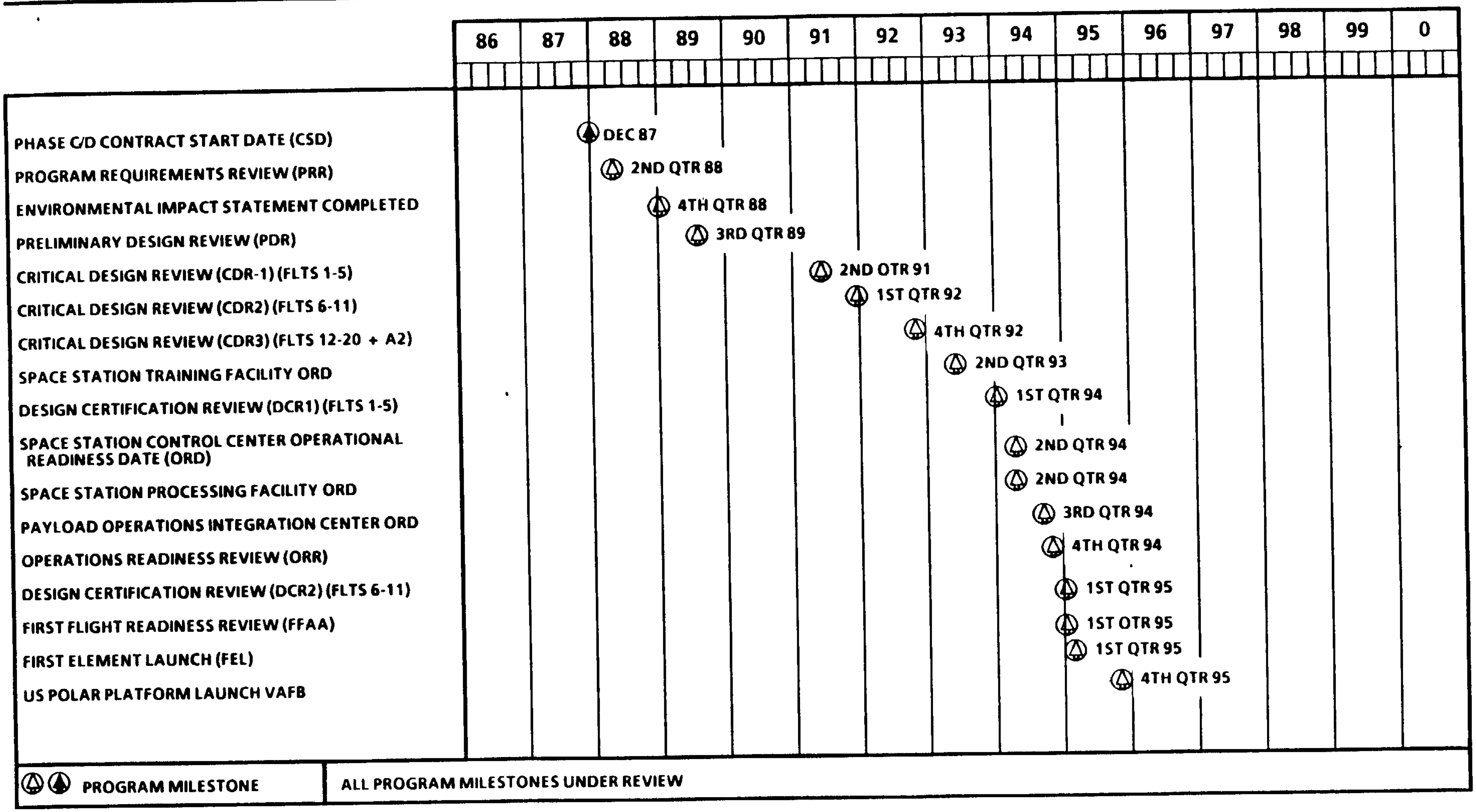

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Figure 2-A
SPACE STATION
PROGRAM MILESTONES

	86	87	88	89	90	91	92	93	94	95	96	97	98	99	0
MAN-TENDED CAPABILITY (MTC)										4TH QTR 95					
DESIGN CERTIFICATION REVIEW (DCR3) (FLTS 12-20 + A2)											2ND QTR 96				
PERMANENTLY MANNED CAPABILITY (PMC)											4TH QTR 96				
ASSEMBLY COMPLETE. PHASE 1													1ST QTR 98		

PROGRAM MILESTONE — ALL PROGRAM MILESTONES UNDER REVIEW

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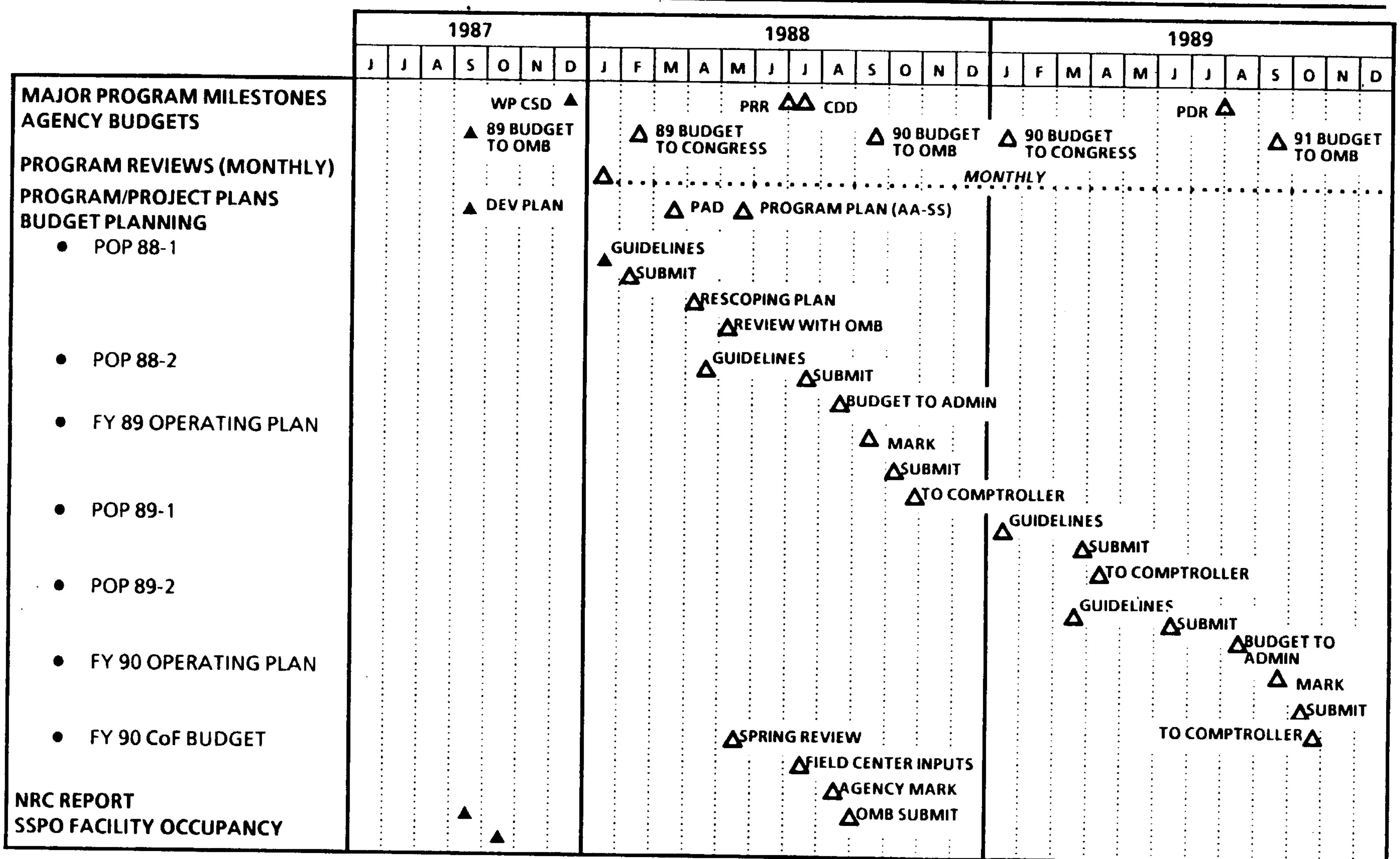
Internal management milestones, Figure 3, are key to the control of the program. NASA realizes that cost control is absolutely central to management of the program, and is determined to track costs very closely. Cost control for the Space Station program is accomplished through a standard NASA system of project or program operating plans (POP). These operating plans are the framework for a detailed assessment of costs at all levels of the program. The POPs are part of an on-going process which provides guidelines to the work package centers, who in turn submit their requests for funding. These requests go through extensive and detailed review at Level III (including by Center Directors), at Level II in Reston, at Level I at NASA Headquarters, at the NASA Comptroller's Office, and at the Office of Management and Budget. Further, NASA is establishing effective cost control mechanisms for both development and operations in order to manage the program within total cost allocations. In this manner, costs are controlled, the NASA budget is implemented, and operating plans consistent with the budget are established. Program progress against the plan is reviewed monthly to assess planned versus actual costs. The program is adjusted within funding constraints semi-annually as necessary.

In addition to the regular POP schedule, thorough "bottoms-up" cost reviews are undertaken on an as needed basis. An internal review of this nature was held in late 1986. Should there be a large, unexplained contractor overun, or unforeseen technical difficulties, further special programmatic cost reviews for the Space Station would be held. Internal cost reviews are supplemented by external assessments.

Other critical budget and management activities include program reviews, budget and resource requirement updates, internal (NASA) and external (OMB, Congress) budget updates, and Construction of Facilities status reviews. Table 3 depicts these milestones for FY 1988 and 1989.

NASA will continue to exert considerable control over the cost and schedule of the Space Station. While it is too early to tell how much impact the budget reductions have had on the schedule, every effort will be made to see that the impact is minimized as much as possible. NASA intends to develop the Space Station in a timely and controlled manner that realistically takes into account both technical and fiscal constraints.

Figure 3
SPACE STATION
INTERNAL BUDGET REVIEW MILESTONES



CDD - CONTRACT DEFINITIZATION DATE
CSD - CONTRACT START DATE

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III. The Baseline Configuration

The baseline configuration description outlined below is intended to provide an understanding of the Space Station design approach, a physical description of what the Station will look like, and an idea of how it will function. The description focuses on the hardware and distributed systems that will make up the Station, with primary emphasis on the U.S. areas of responsibility.

A. General Description

The Space Station Baseline configuration evolved from an extensive analysis of scientific and commercial user requirements, as well as transportation considerations, and engineering and technology factors. The Phase B preliminary design, completed in January, 1987 after 21 months of extensive analysis by both NASA and industry, firmly established an architectural concept for the Space Station configuration. During Phase B, a Critical Evaluation Task Force (CETF) reviewed and validated the Baseline configuration design--the Dual Keel. The Dual Keel was subsequently scaled down to the present Baseline configuration described here after costs were reviewed. The CETF also developed options concerning the assembly process, safety, transportation capability, operations and early productivity. Also, an Operations Task Force established operational concepts to be used in Space Station design.

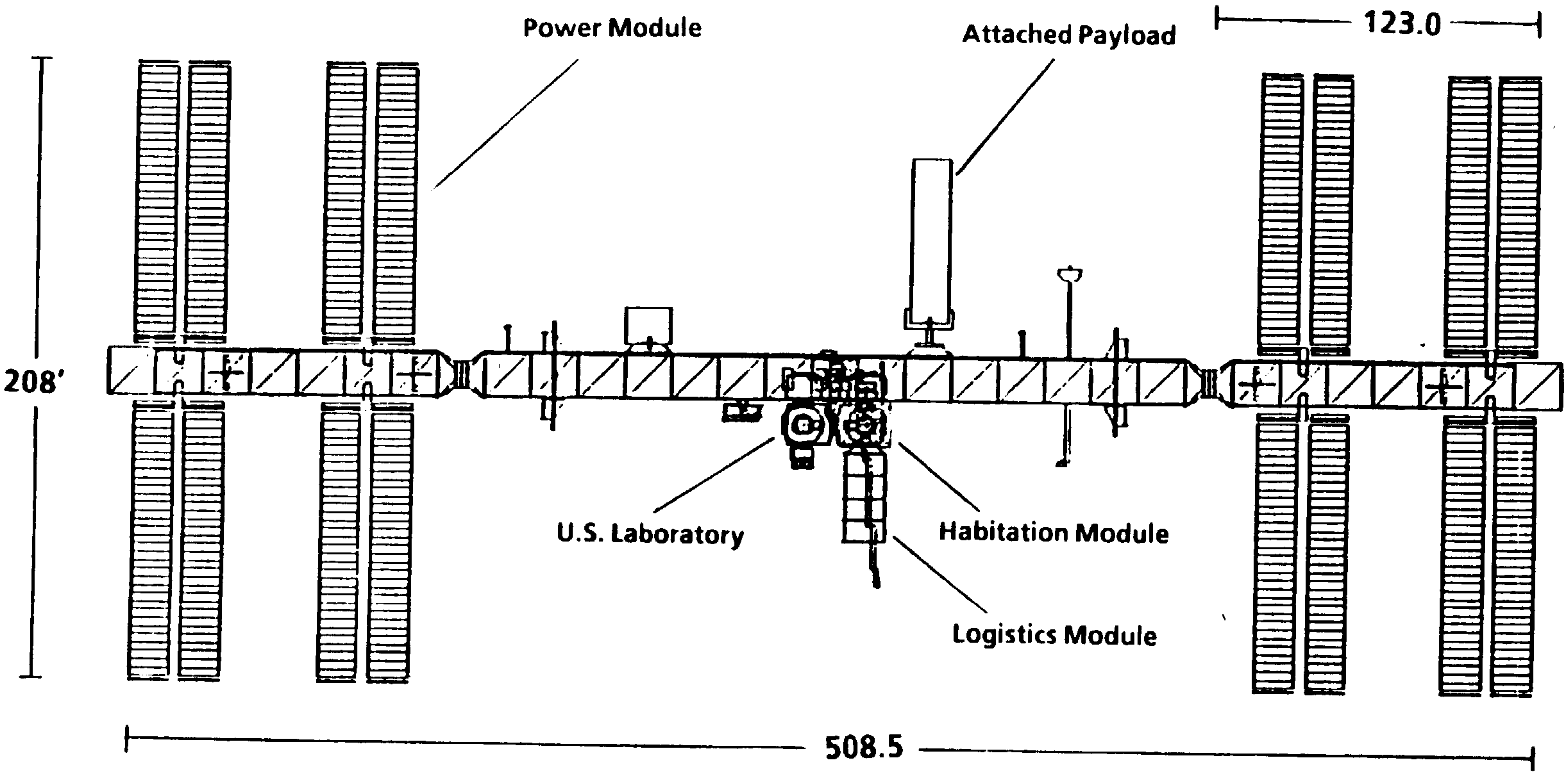
Although the Phase B revised architecture configuration will be used as a baseline for design and development during Phase C/D, the design will mature as the Preliminary Requirements Review (PRR), Preliminary Design Review (PDR) and the Critical Design Review (CDR) are carried out. Therefore, the considerable detail described in this report is subject to change as Phase C/D proceeds.

The Baseline configuration includes a manned core Station and two associated unmanned platforms. These will be polar orbiting platforms, one developed by the United States and one by the European Space Agency (ESA). In addition, ESA will develop a Man-Tended Free-Flyer.

Space Station elements will be held together by attachment to a 262.5 foot (80 meter) long transverse boom flying perpendicular to the velocity vector (see Figure 4). It will be designed to operate from approximately 150 nautical miles (276 km) to 270 nmi (500 km) at a 28.5 degree inclination. The nominal operating altitude will be approximately 220 to 250 nmi. Four pressurized cylindrical modules will be located in the center of the Station. The Habitation module will provide living quarters for up to a crew of eight. The United States, ESA, and Japan will each develop a laboratory module. Also, pressurized and unpressurized logistics carriers will provide supplies and equipment. Finally, there will be limited provisions for payload servicing.

The Station will be powered by two power modules, each composed of two pairs of photovoltaic arrays. The T-shaped 123 foot (37.5 meters) long power modules will be attached to either end of the boom with two alpha joints, which will rotate to point the solar arrays toward the sun. With the power modules, the total length of the Station will be 508.5 feet (155 meters). The power modules will supply an average total of 75 kilowatts (kW) of electrical power. The boom will be equipped with attach points providing power and other utilities to accommodate a variety of external scientific payloads.

Figure 4
BASELINE CONFIGURATION - FORWARD VIEW



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Other features of the Space Station will include a Canadian Mobile Servicing System. This system will be used to assist in the assembly of the Station and for a number of servicing tasks. There will also be a Flight Telerobotic Servicer, which will be used to service payloads and which will also be used in the assembly of the Station.

Space Station elements are the major pieces of hardware that are assembled to make up the Space Station. Elements comprise the hardware of the Station that is not involved with distributing a utility or service. Distributed systems, in contrast, provide those functions whose end-to-end performance is located in two or more elements. The Station will have a number of distributed subsystems which will provide data management, thermal control, communications and tracking, guidance, navigation and control, environmental control, human life support and fluid management. A more comprehensive functional and physical description of Space Station elements and distributed systems follows.

B. Space Station Elements

1. Transverse Boom

The boom will be a 262.5 foot long truss assembly that will give structural stiffness and dimensional stability to the entire Space Station. The truss will also provide the structure for integration and installation of all the elements and systems, including the modules, that make up the Space Station.

The core truss will be a framelike structure made up of longerons, battens, and diagonal struts designed to be assembled in space. These members, made of composite materials, will be attached to corner fittings forming a beam truss of sequential cubic bays measuring five meters wide from strut centerline to strut centerline.

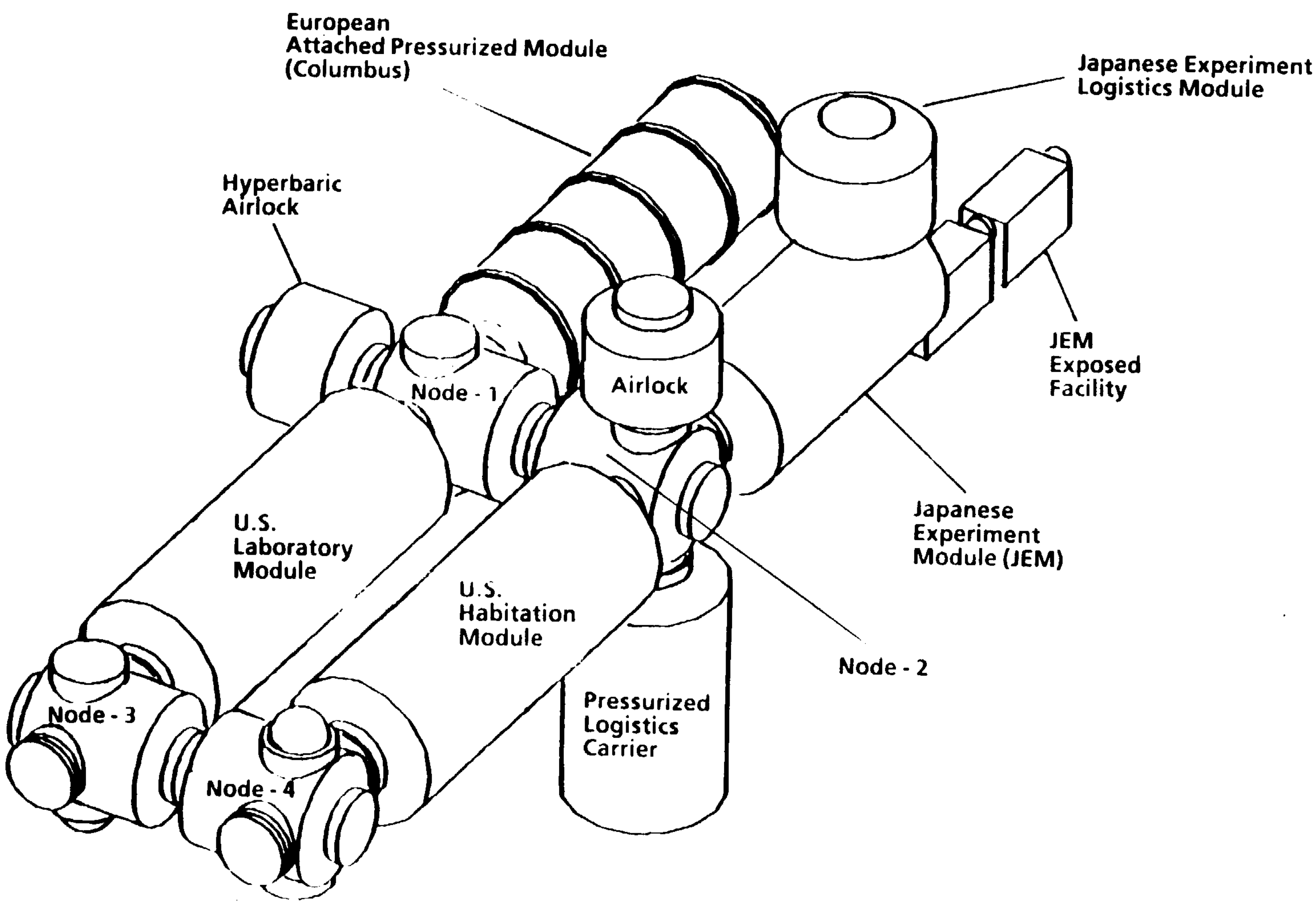
The overall truss assembly will include the core truss structure, EVA (extravehicular activity) truss equipment to facilitate crew movement about the Station, an external lighting system, utility distribution trays, resource pallets, and an alpha joint and drive mechanism used to turn the photovoltaic power modules. Utility distribution trays will house all the subsystem distribution lines--thermal, power, fluid and data management--for the Station. Utility ports, equipped with common interfacing hardware, will be provided for external attached payloads.

2. U.S. Laboratory Module

The U.S. laboratory module will be used to conduct basic microgravity materials and life science research. The experiments conducted there will be those which require low gravity levels over long periods of time, and extensive human control and monitoring. The commercial potential of materials processes in microgravity will also be investigated in the U.S. laboratory module (see Figure 5).

The U.S. laboratory module will be located below the lower face of the transverse boom. It will be attached perpendicular to, and slightly to the right of center, on the boom. The laboratory will be a pressurized cylinder, 14 feet in diameter and approximately 44 feet in length. The ports at either end of the module will be 7 feet in diameter. It, like all the major components of the Space Station, will be designed to fit in the Space Shuttle cargo bay. The ends of the module will attach to Nodes 1 and 3.

Figure 5
PRESSURIZED MODULE CONFIGURATION



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The module structure will be composed of two basic structures and a number of layers. The primary structure will consist of a pressure shell, meteoroid shield, and radiation protection. It will also have Space Shuttle attachment provisions, viewports, and grapple fixtures. The secondary structure will be an inner wall that provides rigidity for attaching experiment racks and other equipment. Utility lines will also be mounted to this structure.

The interior of the laboratory module will be pressurized at 14.7 psi (sea level pressure), and will be able to accommodate up to 42 cubic meters (30 double racks) of payloads and payload support equipment. These payloads and related equipment will be located along the port and starboard walls of the laboratory. The Environmental Control and Life Support System (ECLSS), other distributed system components, laboratory outfitting equipment,and storage lockers will be placed along the floor and ceiling.

3. Habitation Module

The habitation module will be the living quarters for the crew. It will be designed to include safe haven emergency supplies and provisions to allow its isolation from the other modules. The habitation module will be where the crew eats, sleeps, engages in recreational activities, and receives medical care when necessary.

The habitation module will be identical in size and structure to the U.S. laboratory module and will be located parallel and next to it. Like the laboratory, the habitation module will have both a primary and secondary structure. The interior will be outfitted with the means for cooking, eating, personal hygiene, and other human needs. Exact outfitting equipment has not yet been specified. The floor and ceiling will contain stowage areas for spares, consumables, tools for subsystem maintenance, and troubleshooting equipment.

4. European Attached Pressurized Laboratory Module

The European module will be a permanently attached, pressurized laboratory module developed and funded by ESA. The module, 41 feet in length and 14 feet in diameter, will be composed of four segments of all-welded primary structure with axially mounted Station-compatible docking ports at each end. The internal secondary structure will include removable single and double racks for accommodation of subsystems and payloads. The module will also contain a scientific airlock to permit temporary exposure of experiments to a vacuum. The airlock will also be used to transfer tools and equipment to support external activities.

5. Japanese Experiment Module (JEM) and Exposed Facility

Japan will provide the JEM, consisting of a permanently attached, pressurized laboratory module, an exposed facility, and an Experiment Logistics Module (ELM). The pressurized module will be 35 feet long and 14 feet in diameter. The exposed facility will be 25 feet long. The pressurized portion of the JEM will have a structure similar to the U.S. modules. The exposed facility will consist of an open truss and equipment-attach provisions. An airlock will provide access between the pressurized module and the exposed facility. The ELM will provide transportation and storage of supplies, and potentially could serve as a safe haven for two crew members.

6. Resource Nodes

The Space Station will have four resource nodes, located at each end of the habitation and U.S. laboratory modules. The nodes will be small pressurized cylinders that will generally serve as command and control centers, and as pressurized passageways to and from the various modules. The nodes will provide additional pressurized space for the Space Station. They were added to the preliminary design to accommodate early astronaut concerns about the amount of extravehicular activity (EVA) that would be required to assemble the Space Station. By housing a number of Station systems inside the nodes, EVA time was reduced.

The nodes will be pressurized cylinders approximately 14 feet in diameter and 17 feet long. They will be developed like the modules, with a primary and secondary structure and containing accommodations for distributed systems. Certain nodes will also contain berthing mechanisms for temporary attachment of either the Space Shuttle or the logistics modules. They will also have attaching elements to connect the node to the truss and modules. One or more cupolas may be attached to node ports to allow direct viewing of external activities. The nodes will also contain docking equipment and hatches.

As the Station is presently configured, Node 1 will be the unmanned spacecraft control center, controlling both unmanned flights and man-tended operations. It will be located between the Columbus and U.S. Laboratory Modules, and will attach to the hyperbaric airlock (explained later) and Node 2. Like Node 2, it will contain a berthing mechanism to allow the temporary attachment of the logistics module. Node 1 likely will also contain major components of the propulsion subsystem.

Node 2 may be the man-tended command and control station. It will also probably contain the airlock control station and the berthing elements for the airlock. It will be located between the Japanese Experiment Module (JEM) and the U.S. Habitation module.

Node 3 will likely be the primary command and control station for the pressurized areas of the Space Station. It will be located at the forward end of the U.S. Lab module, and will contain berthing mechanisms for the Space Shuttle. This node could also contain such equipment as the control mechanisms for the distributed utility systems, mechanisms for module-to-node interfacing, a control station for proximity operations, a port for pressurized attached payload accommodations equipment, and a backup control station for the Mobile Servicing System (MSS). It will also contain the necessary scars (hardware provisions) for future module pattern growth.

Node 4 could potentially be the proximity operations station, and prime MSS control station. Attached to the forward end of the U.S. Habitation module, and connected to Node 3, it will provide a pressurized passageway to and from the modules. It will contain the NSTS berthing mechanism, and mechanisms for cupola attachment for the proximity operations control station. Like Node 3, Node 4 is scarred for growth.

7. Logistics Carrier

There will be two types of Space Station logistics carriers: pressurized and unpressurized. Both will be used to transport equipment and fluids to the Space Station and to return experiment results, equipment, and waste products back to

Earth. They will be carried in the Orbiter payload bay. The pressurized carriers will transport equipment and supplies which require a pressurized, protected environment. Unpressurized carriers will be used for liquids and equipment which need no pressurization. Both kinds will be reusable.

The pressurized logistics carrier will be located on the nadir of the Station (in the direction of the Earth), berthed either at Node 1 or Node 2. It will be approximately 14 feet in diameter. Its length has not yet been determined. The pressurized logistics carrier will be structured like the nodes and modules. The primary structure will consist of a cylindrical pressure shell with conical ends. It will have both Orbiter and Space Station attachment mechanisms. The secondary structure will consist of a rigid surface for the support of distributed subsystems and utilities, secured stowage, and facilities for interchangeable racks containing spare parts, Orbital Replacement Units (ORUs), experiment parts, and consumables. (Orbital replacement units are modular components of the Space Station that can be easily taken off and replaced.)

The unpressurized logistics carrier will also berth at Space Station ports. It will be designed to carry equipment and supplies that do not require a pressurized, protected environment. This could include ORUs for the Space Station, Station payloads and experiments, and fluids.

A family of designs is being studied for the unpressurized logistics carrier. It will be roughly cylindrical, but size and exact structure of the module has not yet been determined. The diameter will be no wider than the diameter of the Orbiter cargo bay. The length may vary according to the purpose of the particular carrier.

8. Airlocks

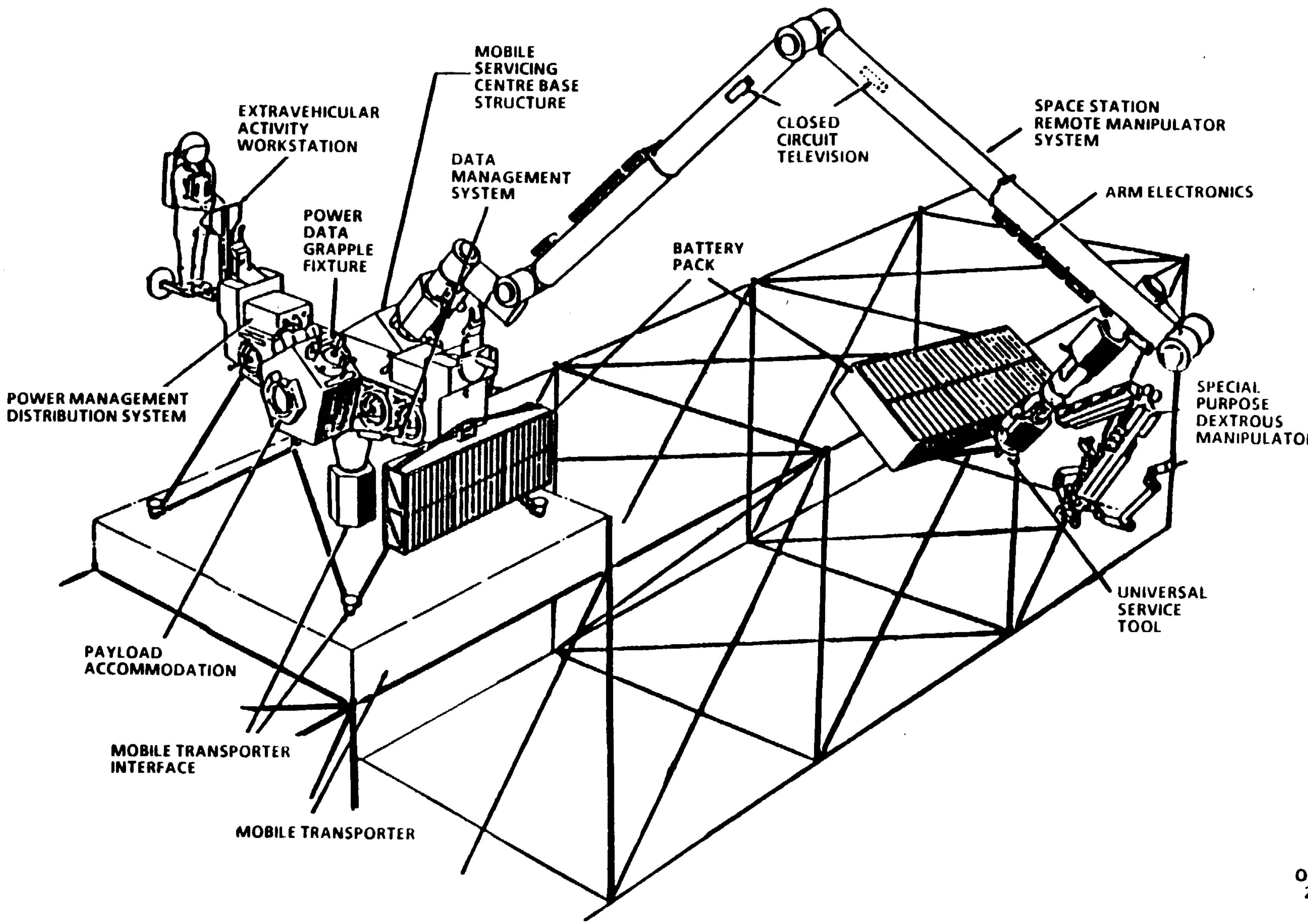
There will be three airlocks on the Space Station: two pressurized at normal sea-level pressure, and one hyperbaric airlock capable of functioning at higher pressures. The airlocks will allow a suited astronaut to enter and exit the protected environment of the Space Station. They will provide depressurization and repressurization, EVA system checkout, service and maintenance equipment, and EVA system storage. The airlock will have access to all the distributed systems and utilities provided to other pressurized areas of the Space Station.

The hyperbaric airlock is a variable pressure airlock that will be used in the event that a crew member needs medical attention for conditions such as altitude decompression sickness or pulmonary embolism (the "bends"). Provisions will also exist to pass items to and from the vacuum of space without loss of pressure in the Space Station. Both kinds of airlocks will be structured like the other pressurized Space Station modules.

9. Mobile Servicing System

The Mobile Servicing System (MSS) will be a automated tool used for assembly, routine servicing, and maintenance of the Space Station and attached payloads. See Figure 6.

Figure 6
MOBILE SERVICING CENTER



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The Mobile Remote Servicer (MRS), provided by Canada, and the U.S.-provided mobile transporter (MT) will make up the Mobile Servicing Center (MSC). The MSC will be the primary element of the Mobile Servicing System. The MT will ride along rails mounted on the truss, providing mobility for the MSC. The MT will alsogenerate its own, or throughput Space Station distributed utilities and data. The base of the MT will measure approximately 16x20 feet. The height has not yet been determined.

The MSC will consist of a base structure mounted on the mobile transporter, a Remote Manipulator System (RMS) similar to the one on the Orbiter, an Astronaut Positioning System (APS), and a Special Purpose Dexterous Manipulator (SPDM) which acts as the "hands" of the system. The APS will be similar to the RMS, except that it will have additional restraints designed to secure a suited astronaut. The SPDM will be designed to perform changeout of Space Station Orbital Replacement Units (ORUs) and attached payloads.

In support of construction and assembly functions, the MSS will remove cargo from the Orbiter cargo bay, transport it to the point of construction or assembly, support EVA assembly functions with flight crew positioning devices, and provide post-assembly inspection. The MSS will also transport Station elements and payloads to locations on the Space Station as well as provide deployment and retrieval functions. It will also support EVA operations and Space Station maintenance.

10. Flight Telerobotic Servicer

The FTS will be a highly automated telerobotic device capable of precise manipulations in space. Phase B Preliminary design for the Flight Telerobotic Servicer is currently underway. Thus, while a functional description is possible, a physical one is not yet available.

The FTS will do routine and hazardous tasks, thereby reducing EVA time and risk. Proposed initial capabilities include installation of truss members, installation of fixtures on the truss, changeout of Space Station ORUs, the mating of the Space Station thermal utility connectors, and inspection tasks.

Astronauts will operate the FTS using both direct manipulator control and programmed command sequences. The FTS will be designed to be operable from several different workstations as the Space Station develops. Its hardware and software will be structured in a modular fashion to ensure serviceability, and its configuration will be flexible enough to facilitate technological upgrade.

11. Attached Payload Accommodations Equipment

Attached Payload Accommodations Equipment (APAE) will be the equipment used to mount and run external scientific payloads. The APAE will include a structural interface between the Space Station and the payloads, and distributed systems outlets to supply the payloads with power, fluids, energy, and data links. The APAE will be designed to accommodate a variety of external payloads, from pre-integrated instrument pallets, to single instruments requiring gimbaled pointing.

There will be two sets of attached payload accommodation hardware that can be used at any of the four utility ports (also called attach points) located along the transverse boom. In addition, there will be one precision pointing mount furnished at any one of the four locations for instruments which must be oriented continuously in a specific direction.

12. Propulsion Assembly

The propulsion assembly will provide thrust for orbit maintenance and three-axis thrust for attitude stabilization and reorientation. That is, three-axis thrust will be used to desaturate the Control Momentum Gyroscopes (CMG) which are the primary attitude actuators of the Stabilization and Control System (S&CS).

The propulsion system will consist of four propulsion modules, a tank farm, and a fuel distribution system. Each module will contain fuel tanks, plumbing and valving, a fuel pump, and two types of jet actuators. The hot gas actuators provide thrust for orbit maintenance. They will be in the 25-40 pound thrust range and will be fueled by a hydrogen/oxygen mixture. The smaller engines used for vernier control will be resistojets in the one pound thrust range. The central tank farm will consist of tankage, valving and a distribution system to the propulsion modules.

C. Space Station Distributed Systems

Distributed systems are those systems whose end-to-end performance is located in two or more elements.

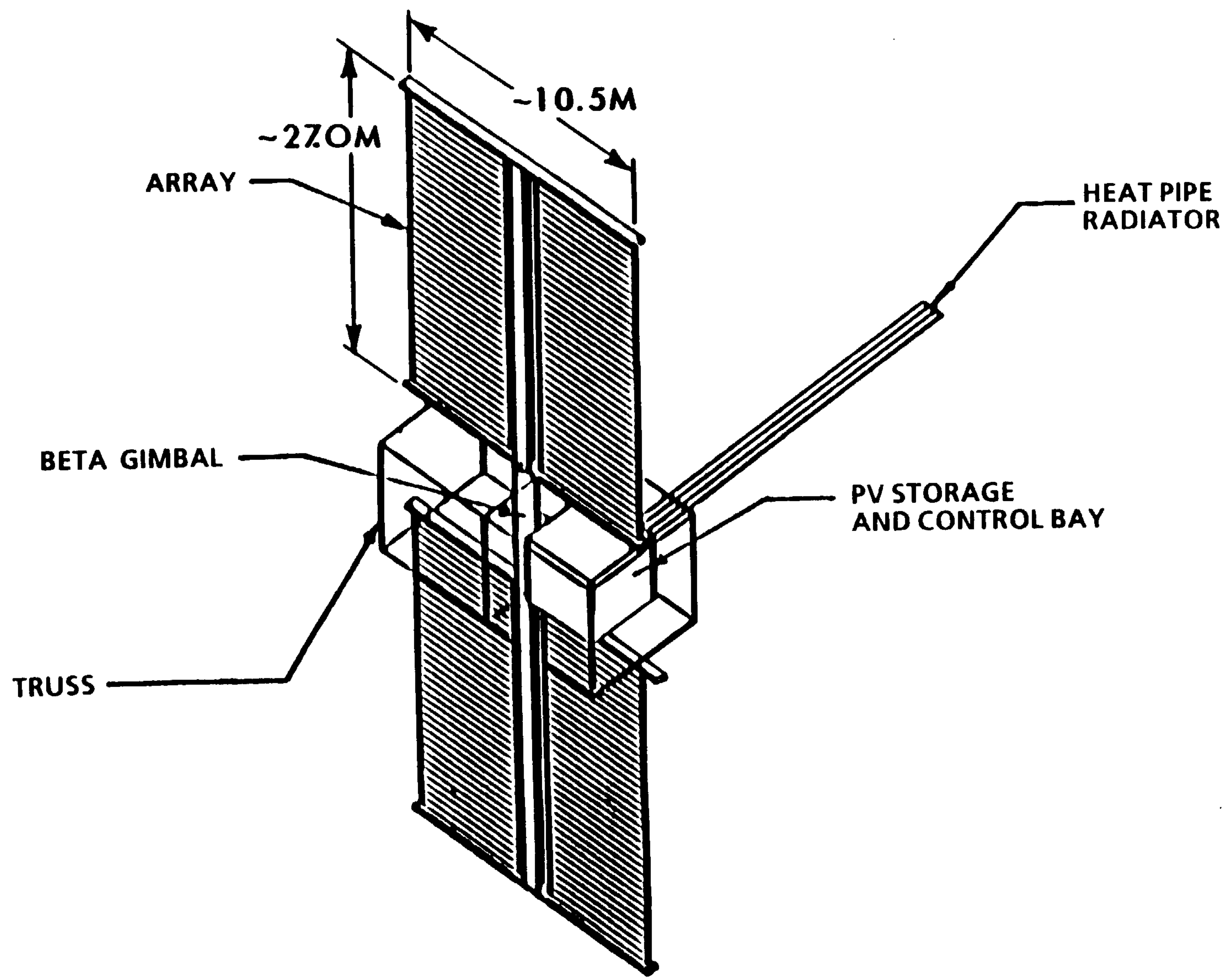
1. Electrical Power System

The electrical power system is a distributed system which will generate and distribute 75 kilowatts (kW) of electrical power to the Space Station housekeeping functions and users. The system will consist of two power modules and a distribution and management system. The power modules can be considered a separate element, but because they are an integral part of the overall power system, they are described here.

The power modules will be located at each end of the transverse boom. The primary structure of the power module will be a truss similar to the boom construction. Each power module will be composed of two pairs of photovoltaic solar arrays. The module will be attached to the boom with a rotating mechanism, the alpha joint, which will provide 360 degrees of rotation to angle the solar array panels toward the Sun as the Station revolves around the Earth. Each solar array will be attached to the power module structure with a beta joint. This joint will provide a second degree of freedom necessary to permit the solar panels to track the sun. The solar panels will be approximately 10.5 meters wide and 27 meters long (see Figure 7).

The power modules will contain nickel hydrogen batteries to store the direct current (DC) power generated by the solar panels for use when the Space Station is in the shadow of the earth. Each power module will also contain power converters to convert direct current to 20 kHz alternating current (AC) for distribution throughout the Space Station. They will also have radiators to dissipate waste heat from the power module.

Figure 7
PHOTOVOLTAIC (PV) POWER ARRAY



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The distribution equipment will include cables, load converters, transformers, regulators, switches and other standard electrical equipment. The overall distribution subsystem will be composed of equipment necessary to process, control, and distribute power to other Station subsystems, elements, and attached payloads.

The electrical primary distribution architecture calls for a modified dual-ring bus system which provides utility power to external areas. Each of the four manned modules will be supplied through one or more resource nodes. Transformers will be used at the node penetrations to provide isolation for the single point ground system and to reduce voltage to the standard value supplied.

2. Thermal Control System

The Thermal Control System (TCS) will control the temperature and heat distribution throughout the Space Station, and vent the heat produced by on-board systems. It will be composed of two parts: a Passive Thermal Control System (PTCS) and an Active Thermal Control System (ATCS). The PTCS will consist of thermal blankets and reflectors which will isolate Station components from the temperature extremes of the space environment. The ATCS will supplement the PTCS.

The ATCS will collect, transport, and reject waste heat from the manned modules and other Space Station elements. The central heat collection and transport will be accomplished using a thermal bus approach. The thermal bus will use a two-phase working fluid to transport heat by evaporation and condensation. This will provide a distributed heat sink function at a constant temperature over the length of the flow circuit. Ammonia and water will be the two working fluids. Ammonia will be used in the parts of the Station external to the manned modules, and for safety reasons, a water loop connected to the ammonia loop will be used internally. The internal loop will operate in the range of 35 degrees Fahrenheit, the external loop, in a range of 70 degrees Fahrenheit. These two central flow circuits in turn will interface with a modularized, erectable central heat pipe radiator system. This radiator assembly, located on the transverse boom, will include a rotary fluid joint that permits the radiator to be rotated away from the radiant heat of the sun.

ATCS control functions will be automated as much as possible to minimize requirements for crew participation. System operating parameters such as pressures, flow rates, and fluid temperature could be controlled by automatic control valves and sensor feedback systems. General system condition, fault detection/isolation, and redundancy management could be controlled automatically in event of component failure. The automatic controller could perform the necessary data processing with standard data processors supplied by the Data Management System.

3. Space Station Information Systems

Space Station information processing and communications capabilities will be accomplished with a network of related systems, collectively called the Space Station Information System (SSIS). Using the on-board Data Management System (DMS) and the Communications and Tracking System (C&T), the SSIS will provide for information flow within the Station for housekeeping and user purposes, as well as to and from earth.

Technically, the Space Station Program-provided portion of the SSIS will be part of the Station infrastructure. As such, it is not entirely a distributed system of the Space Station because many of its component systems will be located on Earth. Nevertheless, it is an integral part of the Space Station program.

The SSIS will provide communication transparency to both the users and operators of the Station. This means the user on earth will in effect have a direct link to the Station even though his data signals will be switched through a complex network. Standard formats and data bases, will permit the user to share operational databases and transport software throughout the SSIS.

In order to illustrate the end-to-end operational aspects of the SSIS, the following example traces a flow of operational or experimental data from its origin at the Space Station to the desired ground-based end point (i.e. a user laboratory or NASA ground control). On board the Space Station, the Data Management System will receive, distribute, process and prepare the data for transmittal to the ground. The on-board Communications and Tracking system will process the data, convert it to Radio Frequency (RF), and downlink it via NASA's Tracking and Data Relay Satellite (TDRS) System . TDRS will receive, process and transmit the data to the ground terminal at White Sands, New Mexico. White Sands will receive and demultiplex the data and transmit it to ground control at NASA centers as well as other ground facilities such as users' laboratories. The process will be reversed for ground-to-space communication.

4. Data Management System

The Data Management System (DMS) will be a distributed system of the Space Station. It will also be an integral part of the SSIS. The DMS will be an on-board computer system which will provide the hardware and software resources necessary to support the on-board data processing and control needs of Space Station systems, elements, and payloads. It will also provide a standardized, homogenous operating environment and human-machine interface for both the Station crew and ground operators.

The DMS will provide a family of compatible computers ranging from a single board computer suitable for use as an embedded controller, to a general purpose processor suitable for hosting system application software. Each processor will have a compatible set or subset of the DMS operating system tailored to its specific application.

The DMS will also include a common assembly called the Multipurpose Application Console (MPAC). The MPAC will be the electronic core of the Space Station work stations. It will provide access into operational monitoring, training, testing, caution and warning display, and crew operations. Some of the MPACs will be fixed in place, others will be portable.

5. Communications and Tracking

The Communications and Tracking (C&T) System will also be an integral part of the SSIS infrastructure. C&T will provide all the communications services necessary to support Space Station and payload operations. These will include command and control, audio, video, and telemetry communication and tracking services, both space-to-space and space-to-ground.

The C&T system will be divided into six subsystems, each representing a major class of service or function. The space-to-space subsystem will provide communication with astronauts performing EVA, with the Space Shuttle, the Orbital Maneuvering Vehicle (OMV), the Mobile Servicing Center, the Flight Telerobotic Servicer and any compatible free-flying platforms in the vicinity of the manned base. The space-to-ground subsystem will provide communication via TDRSS to the ground data networks.

The audio subsystem will provide all of the voice communications on the Space Station. It will be a full duplex system similar to a standard telephone system with conference, record and playback capability. It will provide voice communications between the crew inside the pressurized modules, the EVA crew, the crew of other manned vehicles, and compatible ground systems.

The video system will provide all of the internal and external video capabilities on the Space Station. It will be composed of internal and external remotely controlled cameras. The video subsystem will include closed-circuit television, video storage, retrieval, compression, graphics, and special effects capabilities. On-board distribution of video data will be analog, while video transmission to and from Earth will be converted to digital signals. The subsystem will allow special area monitoring, as well as conferencing between crew locations and between crew and ground. There will be signal processor interfaces between the DMS and the video and audio subsystems.

The tracking subsystem will consist of a Global Positioning System (GPS) receiver/processor with provisions to accommodate future laser docking and radar requirements. The control and monitoring subsystem will manage all C&T resources and distribute the C&T data.

6. Guidance, Navigation and Control System

Guidance, Navigation and Control (GN&C) will provide core system control and traffic management. The core system will supply attitude and orbital maintenance, support the pointing of the photovoltaic power arrays and the thermal radiators, accomplish periodic reboost maneuvers, and provide Station attitude and orbital information to other systems and users. The GN&C traffic management function will control incoming, outgoing, and Station-keeping traffic within the vicinity of the Station. It also will control docking and berthing operations, monitor the trajectories of vehicles and objects that may intersect the orbit of the Space Station and support flight planning.

The core GN&C system will consist of inertial sensor assemblies, star trackers, and control moment gyroscopes (CMGs) located on the transverse boom. CMGs act to stabilize the motion of the Space Station. That is, the CMGs will compensate for the cyclical disturbance torques and will accumulate bias torques. Disturbance capability will be limited and unloaded (compensated for) by the propulsion system. The GN&C will also include standard data processors possibly located in two of the resource nodes. The GN&C System will interface directly with the propulsion system thrusters for reboost and attitude control. Orbital state data will be provided by an on-board Global Positioning System receiver/processor via an interface with the C&T system.

7. Extravehicular Activity System

The extravehicular activity (EVA) system will provide crewmembers with the capability to perform routine tasks in the unpressurized environment on and about the Space Station. The system will support assembly, maintenance, repair, inspection, and servicing of Station and user systems.

The EVA system will consist of a number of subsystems. Central to EVA will be the Extravehicular Mobility Units (EMU). An EMU will consist of a space suit, equipment for communications and physiology monitoring, and an autonomous life support system carried as a backpack.

The EVA system will also include a service and performance checkout subsystem, EVA translation and mobility aids such as handrails, slide mechanisms and tethers, and EVA crew and equipment retrieval and retrieval subsystems servicing provisions. EVA lighting, generic tools, miscellaneous support equipment and lockers, extravehicular contamination detection and decontamination equipment, and systems interfaces for airlock, ECLSS, thermal control and power utilities will also be included in the EVA system. These components and subsystems of the EVA system will be stowed throughout the Space Station elements, with the majority of the equipment being located within the airlocks. Various tools, restraints and work platforms will be located on the Mobile Servicing Center. Mobility and translation aids will also be located on the truss.

8. Environmental Control and Life Support System

The Environmental Control and Life Support System (ECLSS) will provide a habitable environment for both the crew and for biological experiment specimens. The system will maintain atmosphere temperature, humidity, pressure and air composition in the pressurized modules. It will supply potable and hygiene water, and process and store biological waste. It will also be capable of detecting and suppressing fires.

The hardware for the ECLSS will be distributed throughout the pressurized elements of the Space Station. Life critical hardware--atmosphere control and supply hardware required for repressurization, fire detection and suppression equipment--will be located in each of the two U.S. modules to provide redundancy.

9. Fluid Management System

The fluid management system (FMS) will distribute fluids such as water, nitrogen, and waste fluids throughout the Space Station.

The integrated nitrogen system will include all of the hardware and software required to resupply, transfer, store, condition, distribute, control and monitor nitrogen for the Space Station. The resupply subsystem will include the tankage, mounting hardware, conditioning, thermal control, transfer, monitoring and control hardware necessary to deliver the fluid to the Station. It will be located on the truss. Tankage and associated equipment to store the nitrogen will also be located on the truss external to the modules. The distribution subsystem from the resupply to the storage systems, and from the storage tanks to the user interface will also be located on the truss. The latter distribution subsystem will consist of two parts. One part will transfer nitrogen to the ECLSS, the integrated waste fluid (IWFS) system, and an interface with the internal distribution systems located in Nodes 1 and 2. The other part will transfer nitrogen to the integrated water system (IWS) and the laboratories.

The integrated water system (IWS) will be conceptually similar to the nitrogen system. It will contain all the hardware necessary to receive, store, monitor and control the water supply aboard the Station. The storage system, located in the nodes, will be able to accept water from the Orbiter payload bay, from the Space Transportation System (STS) water scavenging system, and from the ECLSS.

The integrated waste fluid system (IWFS) will consist of a collection/distribution subsystem, a storage subsystem, and vacuum vent subsystem. These subsystems will contain all hardware and software required to provide for fluid transfer, storage, conditioning, disposal, control, and monitoring to accommodate gas mixtures and water. The collection/distribution subsystem will receive fluids discarded by the users and will transfer them either to the storage subsystem or to the vent subsystem. The storage subsystem will receive most of the fluids and will retain them for periodic transfer to the disposal interface. The vacuum vent subsystem will receive a small amount of the fluids for disposal in a location which minimizes contamination impacts to the Station environment.

The storage subsystem will consist of plumbing, couplings, regulators, valves, compressors, pumps, tankage, filters, and control and monitoring hardware to provide storage and conditioning of gas mixtures and water. The storage subsystem is located on the truss.

10. Man Systems

The Man Systems (MS) on the Space Station will provide all the hardware and systems necessary for crew habitation and a productive working environment. The MS will be distributed throughout the pressurized modules, but most of the equipment will be in the habitation module. The MS will include 14 subsystems: crewquarters; restraints and mobility aids; crew health care; operational and personal equipment; portable emergency provisions; integrated workstations; galley/food management; personal hygiene; illumination; wardroom; stowage; housekeeping/trash management; interfacing partitions and structures; and tools for in-flight maintenance. These sub-systems are being designed taking into account past experience in these areas on the Orbiter and on Skylab.

The crewquarters will provide accommodations for sleep, rest, and relaxation. Each separate crew compartment will also have some storage space for clothing and personal equipment. They will be designed to allow the crew to have a private space away from the open area of the habitation module. The open area will contain the galley and health care units. The galley will contain all equipment necessary for the preparation and clean-up of crew meals. Consumables and supplies will be stored in the habitation and logistics modules. Safe haven emergency supplies will also be provided.

The health care subsystem will provide equipment and supplies to support all medical, health care, exercise, and environmental health needs. The Health Maintenance Facility will be installed in a dedicated area, and will be tied into the DMS and C&T systems. The hyperbaric airlock will be a part of the health care system. The environmental health subsystem will allow assessment of water and air quality, and contamination.

D. <u>Free-Flying Platforms</u>

1. U.S. Polar Orbiting Platform

The polar orbiting platform will be a self-contained free-flying spacecraft operating in a sunsynchronous orbit at near 90 degrees inclination. Depending on its instrument complement, it will perform Earth biological, geological, and oceanographic observations, lower- and upper- atmospheric monitoring and research, solar observations, and plasma physics measurements.

The platform is being designed in a modular fashion so that it can be tailored to specific missions. It will be constructed, as much as is practicable, with components and orbital replacement units that are common with the Space Station manned base. This commonality will allow cost savings, compared with the cost of developing platform components independently.

The platform will have most of the functional systems described elsewhere in this report. The electrical system will use identical or similar components, including photovoltaic solar arrays, nickel hydrogen batteries, and a 20kHz distribution system. The thermal system will be both active and passive, with ammonia as a working medium in a two phase thermal loop. The data management system architecture calls for the use of similar or identical computers and electronic equipment defined in the Space Station architecture. The C&T system will be compatible with the manned base, and all space-to-ground communication will be via TDRSS. The GN&C system will use inertial and stellar sensors, a DMS general purpose processor, reaction wheels for momentum management and attitude control thrusters for maneuvering the platform.

The polar platform will consist of a propulsion module, a primary carrier, and supplemental carriers as required to support user needs. (Figure 8). Overall approximate size will be 46.9 feet (14.3 meters) in diameter, and 39.4 feet (12 meters) long. The primary and supplemental carriers will accommodate both resource ORUs and payloads. The primary carrier may contain resources not supported by supplemental carriers. It will house all of the power generation capability (via solar arrays and drives) and the standard C&T resources. It will also be the interface to the propulsion module. The supplemental carrier will carry payloads and additional resources, such as batteries and data storage ORUs. Thus, the power and data systems for the Polar Platform will be distributed across its carriers. The thermal system of each carrier will be separate, however, with each one being thermally self-sufficient.

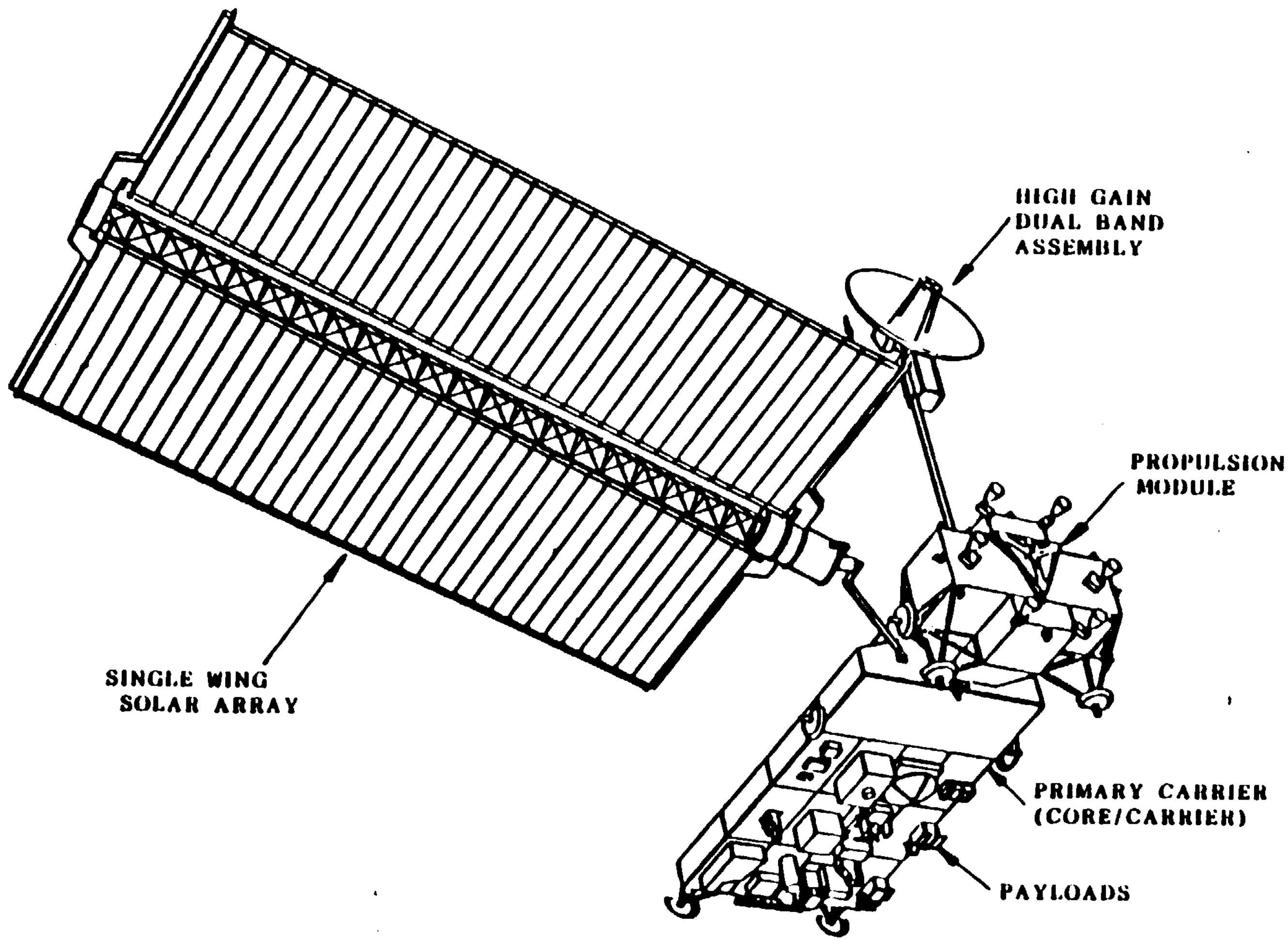
2. ESA Polar Platform

The ESA Polar Platform will be an unmanned free-flyer providing standard resources (power, pointing, and communications) primarily to Earth observation payloads requiring a low-Earth, Sun-synchronous orbit.

The platform reference configuration includes a propulsion modules, a utilities and payloads structure, a two-wing solar array, nickel-hydrogen batteries and radiators, and communications and tracking subsystems. Current studies include backup launch vehicle alternatives, servicing scenario options, and a review of commonality between the platform utilities module and the Man-Tended Free Flyer (MTFF) Resource Module.

Figure 8

U.S. POLAR PLATFORM REFERENCE CONFIGURATION



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3. ESA Man-Tended Free Flyer (MTFF)

The MTFF will be an ESA-built, unmanned pressurized laboratory for long duration microgravity applications in the fields of fluid physics, life, and material sciences. It is being designed for launch by an Ariane 5 into a Space Station compatible orbit with periodic servicing at the Station. The initial Station servicing will not occur earlier than one year following completion of on-orbit assembly of the manned base.

The MTFF will consist of a two-segment pressurized module supported by an externally attached resource module. MTFF payloads will be carried within the two cylindrical segments of the pressurized module which will be identical to those of the Columbus Attached Pressurized Module. Inside the pressurized module will be single and double racks, and a workbench available for crew activities during the servicing period when Station-standard atmosphere is maintained. The resource module will supply the basic power, communications and control for the configuration and houses the ORUs containing the subsystems that supply the MTFF and its payloads with resources. Rollout solar arrays and a deployable antenna will be attached. Attitude control will be maintained through liquid propellant thrusters and cold-gas thruster systems.

IV. NASA Analysis of the Report of the Committee on the Space Station of the National Research Council

A. General Analysis

In September, 1987, the National Research Council (NRC) completed its study of the Space Station Program. The NRC Committee on Space Station was asked by the Administration, first to assess NASA's cost estimates for the Station, and second to examine Space Station mission requirements and alternative configurations. The Committee submitted an interim report in June, and a final, more extensive report in September, 1987. The final report consisted of a number of findings and recommendations.

On the whole, NASA agreed with the NRC's conclusions and is incorporating in Space Station planning a number of its recommendations. NASA was pleased that the Committee judged the NASA Block I Baseline Configuration on balance to be the most satisfactory configuration available. The NRC's support for the Baseline configuration provided an important, independent validation of the Station configuration developed by NASA and industry. NASA, however, did not agree with the NRC's conclusions concerning risk and cost.

The NRC found that the Space Station program is critically dependent on adequate space transportation for its assembly and operations, and that deploying the Station with the Shuttle would be difficult and risky. The NRC recommended that the Shuttle be improved with an advanced solid rocket motor, extended on-orbit capabilities, high operational reliability and availability, and provision be made for an orbiter beyond the Challenger replacement. The NRC also recommended that the nation should develop a heavy lift vehicle in the latter half of the 1990's; that NASA should plan for logistics support of the Station with expendable launch vehicles; and that NASA establish a mandatory requirement for a crew emergency rescue vehicle with possible use on a man-rated expendable launch vehicle.

NASA's request in the President's 1989 budget includes an advanced solid rocket motor, extended on orbit capability, provisions for operational support to meet the planned flight rate build-up and further study on crew emergency escape vehicles.

However, NASA does not believe that the deployment of the Space Station with the current Space Transportation System will be "risky". The NRC came to its conclusion in part based on a plan of 18 Shuttle flights for assembly of the Station, which did not reflect changes in NASA planning which occurred late in the NRC review process. In order to lengthen the period of time related to orbital decay, NASA reduced the weights of the first and second payloads and added another flight to the assembly sequence. This modification will enable the current Shuttle system to deploy the first two Space Station payloads at a higher altitude than previously planned, thus significantly lengthening the period of time before orbital decay would occur. This extra time gives NASA a greater margin in which to correct possible problems on the ground before the partially assembled Station would need reboosting.

NASA also disagreed with part of the NRC cost findings. The NRC reduced its confidence in the NASA Space Station costs estimates during its review because 1) the program was still in flux, 2) there were concerns in the application of cost models, 3) the test program cost estimates may be insufficient as some estimates may have reflected a "proto-flight" rather than a "proto-type" test policy, and 4) the Space Station information system and the strategy for automation and robotics was not well defined. NRC also estimated that increases in the test program and for back up hardware could add from $0.2 billion to $3.9 billion to the Station costs. As a result, the NRC recommended that a new cost estimate be prepared in 1988 based upon the Program Requirement Review (PRR). NASA will prepare a new cost estimate as part of the PRR process. The NRC also identified some cost concerns--particularly regarding cost overruns and growth that might arise due to unforeseen technical problems. The NRC also incorporated NASA projections for institutional support, operations, and transportation into its estimate of the program cost. The NASA figure included only development costs (only those costs associated with research and development) in its estimate of how much the Space Station would cost, consistent with NASA practice to divide its budget according to function, as opposed to defining budgetary categories by individual programs. NASA therefore did not include in its estimate of direct R&D costs the related civil service personnel salary costs, new or modified facilities required, or Space Shuttle flight costs budgeted within the appropriations for Research and Program Management (R&PM), Construction of Facilities, or Space Flight, Control and Data Communication, since these are covered elsewhere in the NASA budget.

NASA believes that the Committee's estimate that the upper range of $3.9 billion may be needed for backup hardware is too high. NASA agrees that additional backup hardware will be necessary. It has already identified backup and test hardware needed for the program which would cost approximately $200 million.

The NRC report correctly states that the Space Station represents, and will require, a strong national commitment. This commitment is vital to leadership in civil space endeavors. The President recognized this fact when he directed NASA to develop the Space Station in 1984 and when he asked for a three year advance appropriation from Congress in the FY 1989 budget request. Congress has been equally supportive, providing both funds and guidance. Independent analysis, such as that performed by the NRC, has also been very helpful.

B. <u>NASA Response to the NRC's Findings</u>

The following contains a summary of the NASA response to each of the NRC's specific findings and recommendations.

1. SPACE STATION CONFIGURATION AND ITS RELATION TO MISSION PRIORITIES AND USER REQUIREMENTS

FINDING:

The early scientific and engineering uses of the Space Station are reasonably well understood. No specific defense or commercial applications have been identified.

RESPONSE:

A basic objective of the Space Station program was to ensure that the facility, as designed and built, would be readily accessible and responsive to the needs of the people who would be using the Station. NASA has had extensive interaction with the user communities which has led to an understanding and accommodation of user requirements. The emphasis on utilization depicted during the definition phase will continue throughout the development phase to assure the integrity of a facility that is first and foremost responsive to the science, technology and commercial user communities.

FINDING:

The Block I configuration is a satisfactory starting point for the Space Station. It reflects thoughtful compromises among the priorities and the sometimes conflicting requirements of its early scientific and engineering uses.

RESPONSE:

NASA agrees. NASA and its partners in industry have made a significant effort, both in time and resources, to establish a Space Station configuration that is versatile, and offers a diverse and substantial set of capabilities.

The Space Station will enable an entirely new class of space research, that of doing science in space rather than just the science of space. The major scientific disciplines to benefit from the Station modules will be the material sciences, as well as some research in the areas of basic physics, chemistry, and life sciences. Astronomical and Earth System sciences will also benefit from the Station's capabilities.

While the NRC Committee correctly notes that the Baseline does not provide all that the life scientists may ultimately need, the Space Station is designed for evolution, including the scenario of adding laboratory modules, if needed.

The Office of Space Science and Applications is developing a Space Station utilization plan, projecting both payloads and budgetary requirements for "science in space." In addition, the office is planning to conduct the research and analyses needed to proceed with extended crew times on Space Station of 180 days (and beyond). The NRC Committee states the baseline configuration has no capability for satellite servicing, construction of large space structures, or for staging manned missions to the moon or to the planets. While the baseline configuration (Block I) does not contain a servicing center, this does not mean that there is no capability to service satellites. NASA has initiated a study to determine how the Block I configuration could support satellite servicing with the use of EVA and with the assistance of an OMV. These studies will be traded off against the capabilities of the Shuttle for servicing. NASA has also initiated a study to determine the modifications required to construct large structures in space. Because the Space Station is an evolutionary facility, it can evolve to provide future capabilities as national needs are identified. NASA believes that major servicing of satellites, and large station assembly and staging could be major functions for an evolutionary Station.

FINDING:

In the absence of agreed-upon long-term space objectives, commitment to a particular configuration for Block II at this time would be premature. Indeed, the next phase of the Space Station could go in any of several directions.

RESPONSE:

NASA agrees. NASA has outlined an enhanced configuration, Block II, that illustrates one way the capability of the Space Station could be expanded in the future. With a new national space policy in effect, the Space Station's current design allows for Station evolution that supports this policy.

Concerning the evolution of the Space Station along the lines of those activities enhanced by the Block II configuration, the NRC Committee states that the Space Station will be in the wrong orbit to serve as a good Earth observation platform. The Space Station manned base will cover about one third of the Earth's surface during its orbits around the globe, and potential Earth science programs, could benefit substantially from the manned base orbit. These include the Earth Radiation Budget Experiment, and other future programs that are undergoing study as part of the Office of Space Science and Application's Space Station planning. Scientific requirements will dictate ultimately the proper orbit and platform for scientific instruments, and NASA will ensure the appropriate instruments are placed in the proper orbits. The Earth Observing System (EOS) missions, if approved, require a polar orbit--that is why this important Earth observation program is taking advantage of the Space Station Polar Platform accommodations.

The NRC Committee also states that the upper and lower booms of the Phase II Configuration may not add much to the Station as a platform for science because most important astronomy and solar system exploration experiments can best be deployed on free flying spacecraft. While free-flying spacecraft may indeed be the optimal approach, the additional structure of the Block II configuration does provide useful accommodations. Of course, NASA is planning to use both the Space Station manned base and free flyers for these scientific disciplines. Many experiments are planned for deployment on free flying spacecraft (e.g., Hubble Space Telescope, Gamma Ray Observatory, Advanced X-Ray Astrophysics Facility, Upper Atmospheric Research Satellite, Cosmic Background Explorer, Extreme Ultraviolet Explorer, Galileo, Ulysses, Magellan, Mars Observer, etc.). Many other proposed future experiments within these disciplines are under study which may take advantage of the unique set of capabilities on the Space Station Manned Base.

A servicing capability in space could continue to grow in value and importance. The National Space Transportation System (NSTS) has begun to develop this capability by establishing servicing standards and tools. The success of servicing repairs performed thus far by the NSTS bear witness to the utility of this activity. NASA is preparing a report to congress on satellite servicing. The evolution of Space Station could further advance servicing and serviceability standards and could offer an extended logistics base, as well as the capability for long servicing periods. These assets could be advantageously exploited by some scientific free flyers and potential platforms.

FINDING:

There is no intrinsic operational and little scientific relationship between the polar platform (now included as part of the Block I Space Station Program) and the Space Station. Prospective users of the co-orbiting platforms (part of the Block II Space Station Program) are likely to gain few benefits from man-tending.

RESPONSE:

NASA agrees with the Committee that free-flying platforms should be evaluated on their own merits, whether or not it is a part of the Space Station Program. However, in addition to the scientific merit, NASA believes there is a possible technical and operational advantage of employing a platform which is based on Space Station data, power and control systems. If the scientific community can tap into these resources by essentially using copies of the Space Station systems, then we could develop the next generation of very powerful free-flyers in a cost-effective manner. For the Polar Platforms, these technical advantages are tempered by the lift mass capability to Polar Orbit and the most cost-effective balance is being pursued. For potential co-orbiting platforms, lift mass is not such a driving issue and operational advantages also become available because of the platforms' proximity to the manned base.

The importance of Station platforms to space research is recognized also by our international partners in the Space Station program. The European Space Agency (ESA) intends to provide a polar platform that will operate in a synergistic manner with the U. S. polar platform.

RECOMMENDATION:

The Administration should clarify its long-term goals in space before committing the Space Station a specific evolutionary path beyond Block I.

RESPONSE:

NASA agrees with this approach, and notes that the new space policy sets forth a series of sensible yet visionary goals.

RECOMMENDATION:

Development of those technologies likely to be needed for any evolutionary path, such as solar dynamic power, should be supported.

RESPONSE:

NASA agrees. NASA's current Space Station plan has been to continue technology development and conceptual design activities on the solar dynamic power system at the Lewis Research Center for application to an enhanced Space Station configuration when additional power is required. NASA is working on other advanced technologies in areas such as automation and robotics that may be required for future evolution of the Station. In addition, the new "Pathfinder" program of technology research and development will provide additional technology that could be used in Space Station evolution.

RECOMMENDATION:

The polar and co-orbiting platforms should be evaluated on their own merits, whether or not carried as part of the Space Station Program.

RESPONSE:

NASA agrees. The scientific merit of the polar platform is evidenced by the strong support for the Earth science program from the U. S. science community, NOAA and the international partners. A key element of the Space Station Program, the polar platform will play a vital role in NASA's Earth science program which will try to gain a deeper understanding of the Earth as a system and the consequences of global change for humanity. A U.S. co-orbiting platform is not currently in the baseline program. Any future decision on requirements for a co-orbiting platform will be based on scientific needs and requirements, and the availability of funding.

2. ALTERNATIVE CONFIGURATIONS

FINDING:

None of the alternative configurations for the Space Station examined by the Committee was judged to be as satisfactory as the current Block I configuration.

RESPONSE:

NASA agrees. NASA has spent considerable effort examining alternative configurations for a permanently manned Space Station. During the 21-month long definition and preliminary design activity, intense analysis by NASA and industry provided strong understanding of Space Station design. The Block I configuration is well defined, and has been extensively reviewed. It effectively balances user requirements, fiscal responsibility and program scope.

FINDING:

Man-tended facilities are not substitutes for a permanently manned Station, although they may play a complementary role.

RESPONSE:

NASA agrees. Man-tended Space Stations were examined extensively during the Phase B definition in direct response to the Congress. NASA concluded that a man-tended Space Station would not adequately accommodate all user requirements. Man-tended capabilities are real, but modest; yet they may require substantial funding to be developed. However, the Baseline Space Station assembly sequence does provide a phase where the Station will be man-tended, enabling useful early scientific research to be conducted before a permanent crew is brought aboard.

NASA has the lead for the Administration in efforts to secure a five year lease as an "anchor tenant" on a Commercially Developed Space Facility. Uses of the CDSF complementary to the Space Station are being developed.

RECOMMENDATION:

Block I should be adopted as the initial Space Station configuration.

RESPONSE:

NASA agrees. NASA believes the NRC's support for the Block I configuration provides an important, independent validation of the Space Station design which has been thoroughly studied for over three years and is the baseline design.

3. SPACE SCIENCE AND THE SPACE STATION

FINDING:

Platforms, other than the Space Station, will be needed by space science, even after the Station is deployed.

RESPONSE:

NASA agrees. Scientific requirements, and the availability of funds, will dictate the most appropriate platform upon which science missions should be accommodated.

FINDING:

Devastating blows have already been dealt U. S. space science by the postponement of missions after the Challenger disaster, which followed a decade with very few major space science missions.

RESPONSE:

The Challenger accident was a severe blow to the nation's ability to place payloads in space, including space science missions. NASA is implementing a mixed fleet to reduce the backlog in space science payloads waiting to the launch, and to provide access to space in the future.

FINDING:

Demands for Shuttle launch services will continue to exceed the Shuttle's capacity. This condition will impact scientific access to space.

RESPONSE:

NASA's recovery from the Challenger accident will not take place quickly. It will require time to reduce the backlog of payloads waiting to be launched in the space. Future access to space will be provided by a mixed fleet approach which will provide launch capability for payloads that do not require the Shuttle's unique capabilities. NASA's request in the President's FY 1989 budget includes funding to expand the use of expendable launch vehicles, primarily in support of science missions.

RECOMMENDATION:

Space science should not be confined to the Space Station. Science requirements should dictate the means of access to space. Space sciences should continue to be supported with dedicated spacecraft and expendable launch vehicles after the Station is deployed.

RESPONSE:

NASA agrees. It has never been NASA's intention to confine science payloads to the Space Station nor does the Agency's planning do so. The Space Station will provide substantial and unique capabilities for a variety of scientific disciplines, including life and materials sciences, fundamental research in chemistry and physics, and selected astrophysics, Earth sciences and solar system research; however, the majority of planetary, solar terrestrial and astrophysics activities will continue to be accommodated primarily by means other than on the Space Station. Science requirements should will dictate the best possible platform from which to conduct the mission. Furthermore, NASA is implementing a mixed fleet concept, including expendable launch services to accommodate science missions that do not require the Shuttle or Space Station's unique capabilities.

RECOMMENDATION:

Appropriate NASA offices should assure that timely and sufficient investments for Space Station experiments are made.

RESPONSE:

NASA agrees that Station payloads must be developed in conjunction with the Station. Major user organizations within NASA (Offices of Space Science and Applications, Space Technology) are identifying payload and budget requirements for the Space Station. Private industry, with the support of the Office of Commercial Programs, has also begun planning for utilization of the Space Station. Congress has been supportive in providing funds for this purpose, and we anticipate that funds devoted to Station payloads will be a regular part of future Agency budget requests.

RECOMMENDATION:

In the short to medium term, every effort should be made to increase access to space for scientific purposes. To this end, the on-orbit duration capability of the Shuttle should be increased and expendable launch vehicles should be used for those missions that do not require astronaut involvement.

RESPONSE:

As stated earlier, NASA is implementing a mixed fleet concept for increased access to space. The FY 1989 request includes expansion of expendable launch vehicles services primarily in support of science missions. An unmanned Shuttle-derived vehicle is also being studied as part of the joint NASA/DoD Advanced Launch System. Currently, NASA has the capability to extend the 7-day nominal duration of the orbiter to 10 to 11 days by the addition of a fifth cryogenic tank set to orbiter vehicle 102 (Columbia). NASA will begin the development of a kit to be carried in the payload bay that will extend the Orbiter stay times to 14-16 days.

4. SPACE TRANSPORTATION AND THE SPACE SHUTTLE

FINDING:

The Space Station Program is critically dependent on adequate space transportation for its assembly and operation. Deploying the Space Station with the post-Challenger Shuttle, while not infeasible, will be difficult and risky.

RESPONSE:

While acknowledging the synergism between the Space Station and the transportation system, NASA does not agree with the NRC Committee that deployment of the Space Station with the current baseline Space Transportation System will be "risky." This finding does not reflect the current state of Space Station planning. NASA has reexamined the capabilities of the post-Challenger STS system and has a high degree of confidence that the Space Station can be successfully deployed with the current Shuttle system. In addition, the Advanced Solid Rocket Motor is being initiated in FY 1989 and is expected to be available to support Space Station assembly.

The NRC Committee cites a concern about the relatively short orbital decay times, in the event of a reboost failure, which persists throughout most of the assembly sequence. A detailed examination was conducted by NASA that resulted in the development of a modified assembly sequence that will be utilized to give NASA an even greater degree of confidence in the ability of the STS to successfully assemble and support the Space Station. These data, which delineated the increased margins provided by the modified assembly sequence, were not presented to the NRC Committee in time to be fully evaluated and incorporated into the final report. The 50-day decay time mentioned in the NRC report is based on earlier data that indicated that Launch Package-3 would decay in the order of 50 days in the event of a reboost failure if it were deployed at 190 nautical miles. The revised assembly sequence, provided later to the NRC, indicates that Launch Package-3 would be deployed at 220 nautical miles, resulting in an orbital decay time of 230 days.

The parameters affected in the margin optimization are:

- Assembly altitude.
- The mass margin in each Launch Package.
- The extent that the mass margin is used to deliver payloads.

NASA, of course, will continue to examine and refine launch packages and the entire Space Station assembly sequence. Current studies suggest that Launch Package-4 should also be deployed at 220 nautical miles. The integration of Launch Packages 1-4 will provide a fully quad-redundant propulsion and reaction control system. Once this redundancy is achieved, the probability of a total propulsion system failure is extremely small. Each subsequent Launch Package will be reexamined in order to examine the optimal assembly altitude coupled with the appropriate mass margin.

RECOMMENDATION:

It is highly desirable that the post-Challenger Shuttle be improved in performance while maintaining or increasing its reliability level. Advanced solid rocket motors with improved performance and reliability should be developed for the Shuttle.

RESPONSE:

NASA agrees that the development of an Advanced Solid Rocket Motor (ASRM) would simplify the deployment of the Space Station and provide additional margin. NASA has released requests for proposals for both definition and preliminary design contracts for an advanced solid rocket motor. ASRM development funding is a high priority element of NASA's request in the FY 1989 President's Budget.

RECOMMENDATION:

NASA should assure high operational reliability and availability for the Shuttle, and should establish operational specifications for Orbiter replacement, spares, accommodation of downtimes, and recovery strategy.

RESPONSE:

NASA has established a Headquarters safety program which has developed a centralized safety program for the agency, instituted Level I safety review and approval roles and responsibilities, and implemented a safety program which focuses on prevention. Considerable effort has been put into the review and examination of risk management and assessment. Earlier this year, we conducted a review of risk management functions and techniques used throughout industry which resulted in the assembly of an ad hoc committee of NASA and industry experts to examine various risk assessment methods and applications. Visits were made to Department of Energy (DOE) and nuclear industry contractors to gain further knowledge of Probabilistic Risk Assessment (PRA) techniques. As a result of our efforts in this area, we have established a risk management policy for manned space flight programs and issued a NASA Management Instruction, "Risk Management Policy for Manned Flight Programs" (NMI 8070.4, February 1988). This policy states that the latest proven analytical techniques are to be used in the development and operation of safe and reliable space systems. The policy provides for a variety of quantitative and qualitative analyses and establishes a hierarchy of methods as follows: qualitative methods such as hazard analysis and Failure Modes Effects Analysis/Critical Items List (FMEA/CIL); a hazards categorization and prioritization system based on engineering judgment; qualitative fault tree analysis; and the use of quantitative risk analysis methods where sufficient data bases exist. In FY 1989, we plan to continue to strengthen this area of SRM&QA, including: the completion of a risk management handbook for the NASA centers, a risk management program plan for the NSTS, development and issuance of a risk management NMI for unmanned programs and the development of a risk management NMI for facilities and aeronautical systems.

RECOMMENDATION:

Provisions should be made to produce a Shuttle Orbiter, after the Challenger replacement, for delivery before Space Station deployment begins.

RESPONSE:

NASA has based the deployment and routine resupply of the Space Station on a four-Orbiter fleet. We remain confident that the current fleet is adequate to support the Space Station Program. NASA's mixed fleet concept provides the flexibility to augment the transportation system depending upon user and budgetary requirements. The requirements for additional Orbiters and ELVs will be continually addressed in the future.

As pointed out by the NRC, a robust transportation system is important to pursue an aggressive manned space program.

In addition, NASA believes that a four-Orbiter fleet is required to fulfill the Agency's total space transportation commitments. However, maintaining this fleet demands that a replacement Orbiter plan be established. Two modes may be considered for the replacement orbiter plan. One mode may be the one recommended by the NRC, that is to plan for the periodic replacement of an orbiter. The replacement interval, however, is not determined and may be different than the 5-8 years specified in the NRC report. An alternative, and possibly more cost-effective, concept is to maintain the assembly line by the procurement of a robust spares complement. Initiation of procurement for structural spares is planned for FY 1989.

RECOMMENDATION:

Extended duration on-orbit capabilities should be provided on one or more of the orbiters.

RESPONSE:

NASA will initiate development of an extended duration capability in 1988. One such Orbiter is planned to be modified to carry such a kit.

RECOMMENDATION:

The nation should develop a Heavy Lift Launch Vehicle (HLLV) for use in the latter half of 1990's to permit the launching of payloads larger than those of the Shuttle and to enhance the robustness of the space transportation system.

RESPONSE:

NASA is participating with the Air Force in the definition and development of an Advanced Launch System (ALS). The joint NASA/DoD plan, recently approved by the President, focuses on a new vehicle operational in the late 1990's.

RECOMMENDATION:

NASA should make plans for eventual logistical support of the Space Station with expendable launch vehicles, as well as with the Shuttle.

RESPONSE:

NASA agrees. NASA is currently defining how best to use ELVs to provide logistics support to the Space Station in the mature operations phase of the program.

RECOMMENDATION:

NASA should establish a mandatory requirement for a crew emergency rescue vehicle and should consider its use, on a man-rated expendable launch vehicle, as a backup means of manned access to the Space Station.

RESPONSE:

NASA plans to examine the requirements and configuration of such a vehicle starting in 1988. The requirements for a CERV, the potential application of man-rated ELVs, and other methods for ensuring crew safety, will be identified based on the data gathered during the study phase.

5. SPACE STATION TEST PROGRAM AND BACKUP HARDWARE

FINDING:

The Committee believes that the Space Station test program and backup hardware policy were inadequately defined at the beginning of its study. It believes that NASA has since made progress in both areas, but NASA must continue development of a test program and backup hardware policy, if it is to improve the resilience of the Program.

RESPONSE:

NASA has defined a test program which includes the utilization of flight and flight type hardware, and flight hardware simulators, to verify the preflight integrity of Space Station components and flight packages prior to launch. NASA has also accounted for a large amount of prototype, and a limited amount of protoflight, hardware in the current Space Station Program. NASA will again assess test program and backup hardware plans, utilizing data provided by the Space Station development contractor, during the Program Requirements Review early in 1988.

RECOMMENDATION:

Because of the complex and potentially unanticipated interactions among the Space Station systems, a prototype, as opposed to a protoflight, test program should be employed to the maximum extent practicable. (A prototype program involves the production of two substantially complete sets of hardware--one for ground testing and one for flight. A protoflight program would have only one set used for both purposes).

RESPONSE:

NASA currently has a large amount of prototype hardware, and a limited amount of protoflight hardware, in the Space Station test program. NASA's cost estimates reflect this philosophy of largely prototype equipment for manned elements, and protoflight equipment for the unmanned elements. As part of the Program Requirements Review (PRR) scheduled for 1988, NASA will validate the appropriate application of protoflight hardware considering program risk, cost and schedule.

RECOMMENDATION:

A centralized Space Station Test Bed duplicating, to the extent practical, the configuration of the Space Station on orbit should be retained on the ground.

RESPONSE:

NASA agrees that system test beds which simulate the flight hardware are essential, and a number of them are included in the Space Station Program. The degree to which the test beds are all co-located must be determined based on the capabilities (i.e., vacuum chambers, etc.) current availability, their location, the priorities for new test beds and the availability of funds. Further, NASA is examining options for using the Commercially Developed Space Facility as a man-tended space test bed, in support of Space Station development activities.

RECOMMENDATION:

Each launch package should undergo pre-launch integration, using the Space Station test bed.

RESPONSE:

NASA has a plan in place to perform prelaunch checkout at the launch site using flight or flight-type hardware and simulators to verify the prelaunch integrity of each launch package.

RECOMMENDATION:

Backup hardware to replace flight equipment that might be lost during the deployment phase should be procured. NASA needs to develop an understanding of contingency scenarios in order to determine the backup hardware required.

RESPONSE:

NASA agrees. NASA will continue, as part of its planning process to assess the need for, and phasing of contingency hardware and long-lead items such as forgings, which would cost approximately $200 million.

6. SPACE STATION COST ESTIMATES

FINDING:

Analyses by the Committee during the second phase of this study have, on balance, decreased its confidence in NASA's cost estimates, as presented in the Committee's June 30, 1987 report. For example, up to $3.9 billion in research and development funds over those noted in its earlier report -- almost a 30 percent increase -- could be needed to enhance the test program and to buy backup hardware. Additional growth could arise from difficulties not now identified. [The NRC reduced its confidence in the NASA Space Station costs estimates during its review because 1) the program was still in flux, 2) there were concerns in the application of cost models, 3) the test program cost estimates may be insufficient as some estimates may have reflected a "proto-flight" rather than a "proto-type" test policy, and 4) the Space Station information system and the strategy for automation and robotics was not well defined. NRC also estimated that increases in the test program and for back up hardware could add from $0.2 billion to $3.9 billion to the Station costs. As a result, the NRC recommended that a new cost estimate be prepared early in 1988 based upon the Program Requirement Review (PRR).]

RESPONSE:

NASA strongly disagrees with the finding. As was addressed in the preceding section on Space Station Test Program and Backup Hardware, NASA has a large amount of prototype hardware reflected in the current cost estimate, and it has developed a cost-effective test plan that properly balances the use of flight and flight-type hardware and simulators to perform preflight and launch package checkout. In the area of concern to the NRC--test program and backup hardware--the only area where NASA can currently foresee a potential cost increase is for procurement of contingency hardware, such as large structural spares, that would be needed in the event such hardware is lost during manufacture, launch or assembly. This additional contingency hardware would cost approximately $200 million. Analysis of the need for this contingency hardware is underway and will be completed at the PRR.

The Committee's report states their review of the cost model used at the Marshall Space Flight Center and the application of this model reduced confidence in cost estimates for Space Station hardware under the control of Marshall. The PRC model used by MSFC is a valuable model that relates NASA prior experience to a future program. Adjustments and weighting factors must be applied in the use of the model for the Space Station based on the applicability of prior experience to the Space Station. NASA believes the MSFC estimates were a valid, useful input to the estimating process. The NASA estimates presented to the Committee resulted from an assessment of several estimates by Marshall and the Johnson Space Center. These estimates more than cover the contractors estimates, plus a reasonable amount of uncertainty in their estimates.

The Committee also stated they did not believe the Space Station Information System was well defined, nor was the related automation and robotics strategy for the Space Station. NASA disagrees with the Committee on these two points. At this time, Program estimates can only be based on system design requirements and detail design concepts. NASA believes that both are well advanced, providing sufficient information available to support the current estimates.

NASA wishes to emphasize that the Space Station Information System (SSIS) is well defined. The SSIS Systems Engineering and Integration (SE&I), which has been based on parallel industry definition studies, has defined the sub-networks (e.g., the Data Management System (DMS), the Communication and Tracking (C&T) System), in considerable detail. The open system approach to networking within the SSIS and our use of international communication standards of the International Standards Organization/Open Systems Interconnect (ISO/OSI) Model and the Consultative Committee for Space Data Systems (CCSDS), are a well founded basis for information flow for the SSP and NASA as a whole.

In the area of automation, NASA envisions greater use of artificial intelligence, expert systems, and other forms of advanced automation as confidence is gained in the technology and applicable areas are identified. In the initial configuration of the Space Station, NASA plans to automate the control of several Space Station resources such as electrical power, thermal management, environmental control and life support, and communication and tracking. For example, power system functions that historically have been done manually will be automated on the Space Station, including activities such as load shifting, bus ties, fault detection and isolation, and system reconfiguration.

It is envisioned that expert systems could play a major role in planning, scheduling, and diagnostics. NASA is pursuing parallel technology development and demonstration program as an extension of the Advanced Development Program and coupled with the technology research sponsored by the Office of Aeronautics and Space Technology (OAST). A major focus of the Transition Definition Program within the Office of Space Station (OSS) is to identify and accommodate automation and robotics capabilities for the Space Station.

As part of the Space Station Program's robotics effort, the Flight Telerobotic Servicer (FTS) will be developed. It will, of necessity, serve as a focal point to nurture all of the technologies associated with Automation and Robotics (A&R). The system is designed to facilitate autonomous operations in the future. In this mode, it will use embedded computers with artificial intelligence software operating under the overall supervision of a human operator.

FINDING:

The level of definition of the Station operations concept does not permit the estimation of steady state operating costs with much confidence.

RESPONSE:

NASA has recognized the need to develop operational cost estimates, and, at the time of the NRC report, had a team developing those cost estimates. These have now been identified and presented to the NASA Administrator. NASA will continue to refine and develop more definitive operations cost estimates.

RECOMMENDATION:

NASA should make a new Space Station cost estimate in early 1988. During this exercise, uncertainties such as those in costs of the test program and for backup hardware should be addressed.

RESPONSE:

NASA agrees. A new assessment of program costs are underway.

RECOMMENDATION:

Increased attention should be focused on estimating and controlling Space Station operating costs, so that these do not absorb a significant portion of the civilian space budget.

RESPONSE:

NASA has focused on operations costs from the beginning of the Space Station program, and will continue to do so. A special report to Congress on this subject was submitted in October, 1987. In addition, in the Fall of 1986, NASA established a special Operations Task Force which has now completed an extensive review of Space Station operations. Copies of that report were supplied to Congress. The report forms the basis of the agency's approach to operations cost management, which is a key dimension of the program's overall management systems. In addition, NASA is developing approaches to establish effective cost control mechanisms for both development and operations to manage the overall program costs within its allocation of funds.

7. MANAGEMENT OF THE SPACE STATION PROGRAM

FINDING:

The management challenge presented by the Space Station Program is at least as critical to the Program's success at its technical challenges.

RESPONSE:

NASA agrees. Given the breadth and depth of the Space Station Program, NASA has put in place a strong and stable organization to manage the program during the detailed design and development phase.

FINDING:

NASA has moved to strengthen Space Station Program management, but additional steps are required.

RESPONSE:

NASA established a new Space Station organization in the summer of 1986 which features a centralized management structure, highlighted by a new technical program office established in Reston, Virginia. NASA will have a strong systems engineering and integration capability, supplemented by a support contractor, to manage the heavily interdependent Space Station work packages. And considering the strong imperative to achieve economy, as well as authoritative central control this organization uses the Field Centers' institutional capabilities and does not attempt to duplicate them. The management and technical structure for the Space Station Program will provide leadership to the project with clear lines of authority and accountability, maximize the use of the capability and competence that resides at each participating NASA Center, efficiently integrate the complex changing conditions during the development process, and result in the development of a safe, reliable and cost-effective Space Station.

The Committee states the provision for integration and test, and component flows among Centers is too complex. NASA recognizes the complexity of the integration, test and component flow process among the Centers, but believes its essential to maximize the benefits of commonality. NASA is continuing to trade-off the cost versus benefit of commonality, and will revisit the inter-Center delivery requirements with the hardware contractors once the development phase of the Program is underway. We expect to be able to provide an orderly solution to this complex issue prior to the PRR which is now targeted to begin in April 1988.

FINDING:

The Committee is not satisfied that the current arrangements to coordinate Space Transportation and Space Station Programs are adequate.

RESPONSE:

NASA recognizes the high degree of coordination that must take place between the Space Flight and Space Station Programs. A coordinating committee, chaired by the Associate Administrators of the respective organizations, has been established and meets regularly. Also planned is a project office-level committee, chaired by the respective Space Flight and Space Station Program Directors, which will meet regularly to identify issues which affect the two Programs and resolve them. In addition, a formal launch and assembly plan for the Space Station will be developed jointly by the two offices.

FINDING:

The Committee believes more attention must be paid to managing the operational characteristics of the Space Station.

RESPONSE:

NASA has examined Space Station operations characteristics, and will continue to do so during development. Operational considerations drove various design requirements, such as the propulsion and life support system. An Operations Task Force reviewed Space Station Operations Plans for six months and has issued its report which serves as a baseline concept for the program. The Task Force's analysis includes a description of key operational functions, a discussion of their inter-relationships, product flows and a review of roles and responsibilities. The Task Force report constitutes a significant piece of Space Station analysis and will provide both a framework and path for our planning. The concept developed by the Operations Task Force is helping better understand, anticipate and control operational costs. NASA has also updated the Congressionally required report on Operations Cost Management. This updated report was submitted to Congress in October. The Plan identifies key operations cost drivers to assist NASA in managing these costs to make the Space Station affordable to use and operate. As stated earlier, NASA is developing approaches for operations management and mechanisms for effective control of operations costs.

RECOMMENDATION:

NASA management must emphasize that the Space Station Program Director is the principal line manager of the Space Station Program and is accountable for the successful development of the Space Station.

RESPONSE:

NASA concurs in this recommendation and that is currently the way the Office of Space Station is structured, based on recommendations made by General Sam Phillips who reviewed Space Station management in detail in 1986. NASA believes this is an appropriate organizational structure to ensure clear lines of authority and accountability, and will constantly reinforce this concept.

RECOMMENDATION:

The Committee recommends that NASA establish a dedicated Space Station project organization that would subordinate all personnel assigned to the Space Station to the Program Director and give the Program Director control of financial and other resources assigned to the Program.

RESPONSE:

The Space Station Program Office in Reston, VA, with subordinate project offices at the Field Centers, was established based on the recommendations of General Samuel Phillips following his review of NASA management. This organizational structure and associated responsibilities were established after review and acceptance by NASA Headquarters and top Center management. The Program Director does control financial and other resources.

RECOMMENDATION:

An improved liaison structure between the Space Transportation and Space Station Programs should be developed as part of the management study called for below.

RESPONSE:

As noted earlier, NASA has taken a number of steps to increase and strengthen the relationship between the Space Flight and Space Station programs, including the establishment of a standing Space Flight/Space Station working group, chaired by the respective Associate Administrators for the two organizations, which meets regularly.

RECOMMENDATION:

An organizational entity, independent of the Space Station development hierarchy, with the ultimate responsibility for operating the Space Station should be formed promptly to assure greater attention to operations during the design phase.

RESPONSE:

General Phillips' review of Space Station management also addressed the need for a strong operations organization and resulted in the Administrator establishing an Associate Administrator for Space Operations. The roles and responsibilities of this new organization are under review at this time. A management plan for the Space Station is being developed which will address operations management.

RECOMMENDATION:

NASA should simplify the structure now envisioned for relations between the Station operators and the users of the Space Station.

RESPONSE:

The relationship between the users and operators was thoroughly addressed as part of a Science Operations Management report which was submitted to Congress last fall, and was also examined by the Operations Task Force. Specific recommendations by members of the scientific community on the mechanism by which science activities should be accommodated and operated on the Station were made in the report. NASA has accepted many of these recommendations and will respond to the remainder in the coming year as the management plan is developed.

RECOMMENDATION:

A realistic Space Station development budget should be determined and funds provided in a series of multi-year appropriations, thereby giving long-term financial predictability to the Program.

RESPONSE:

NASA strongly endorses this recommendation. Multi-year funding would provide the required budget stability to the program and help ensure an efficient, cost-effective development effort. A major proposal by the President in his budget request for NASA in FY 1989 included the request for an advance appropriation commitment by Congress to funding the Space Station for FY 1990 and FY 1991.

RECOMMENDATION:

The Committee recommends that NASA, under the general supervision of the Office of Management and Budget (OMB), conduct a study analyzing the Committee's program management recommendations and concerns. A management plan, expressing how NASA intends to respond to the

Committee's management concerns, should be developed as part of this study. An assessment of NASA's progress against this plan should be carried out at an appropriate time.

RESPONSE:

NASA has reviewed carefully all of the NRC Committees recommendations and findings, including those dealing with management. How the agency responds to these varied suggestions and observations is the subject of this section of the Capital Development Plan. Gen. Phillips' overall management recommendations regarding the Space Station Program have been implemented, and because NASA believes the new Level I - Level II management structure needs to be given time to work. Yet, at the same time, NASA realizes that management policies and practices require continuing examination and adjustment. NASA therefore will hold quarterly budget reviews with the Office of Management and Budget, and plans to prepare, in consultation with OMB, a Space Station management plan and staffing study.

C. Alternative Configurations Presented to the NRC

The NRC examined several alternative configurations, most of which were rejected by NASA for a variety of scientific and engineering reasons. Each of the configurations considered, however, added to NASA's knowledge base, providing stepping stones to the current Space Station configuration. The revised baseline configuration (Block I) was chosen as the best configuration because it offered the best compromise between cost, technical capability and engineering difficulty. This configuration also supports those user requirements that are currently well-defined and that will have near-term fiscal support. In addition, it offers the best foundation from which to begin future evolutionary design paths. Such evolution will occur as specific future mission requirements are identified.

The Baseline configuration represents the lowest cost option for a permanently manned Space Station with significant capabilities. Such capabilities include provisions for human interaction with life sciences and materials processing research. This configuration also allows ample opportunities to learn how to assemble large structures in space--needed for future astronomic observation platforms and for future evolution of a permanently manned base in space.

The following is a description of the configurations NASA presented to the NRC. These configurations focused on those considered in the Space Station Task Force Concept Development Group in 1983-1984. The group included representatives from all NASA centers and 12 contractors. During the 1984 development of the Phase B RFPs for the detailed definition of the preliminary design of the Space Station, 3 of 5 candidate concepts were chosen for detailed study (see Figure 9). The three included the Delta, Concept Development Group - Planar, and the Power Tower configurations. Of these, the Power Tower was chosen as the reference configuration for Phase B. For reasons which will be explained below, the Power Tower concept evolved to the Dual Keel configuration (see Figure 10). Because of budget constraints, the Dual Keel was later scaled down to the present revised baseline configuration (see Figure 11).

The major configuration requirements used as criteria in the selection related to power levels, celestial and earth observational capabilities, growth accommodations, volume and provisions for a crew size of six or more. The configurations were also to have scientific airlocks.

The following is a description of each of the five major candidate concepts, including their primary assets and liabilities. For reference purposes, a brief description of older configurations, representative of space station conceptualization since the 1950s, is also provided. These configurations were also presented to the NRC.

The following two configurations were eliminated early in the examination.

Spinning Solar Array - This configuration would fly in an inertial mode using a large spinning solar array to provide an inherent gyroscopic stabilization. The pressurized modules would be suspended in the center on a bearing which would keep the modules from rotating. The principal advantage of this configuration was its generation of artificial gravity. The configuration also provided structural stiffness to the solar arrays due to the centripetal acceleration they would experience. The disadvantages were numerous. First, the configuration would be nearly impossible to assemble in space, and there would be no way to launch it fully assembled. Second, there would be potential health problems for the crew of continuously adapting to highly different levels of gravity at different parts of the Station. Nor would this configuration provide the optimum microgravity environment for scientific experiments. Third, there was no flexibility of evolution; once assembled, no new power sources or pressurized volume could be added.

Big T - The principal characteristics of this configuration are the gravity gradient stable flight mode and the large solar array with only one degree of movement to track the seasonal variation of the Sun. The Big T would provide a very stiff configuration, and hence, be very stable. The evolutionary capabilities for this space station would be limited, however.

The following three configurations were extensively studied before the start of Phase B.

Delta - This configuration features a large sun-fixed, rotating structure in the shape of a Delta made up of a tetrahedron truss. A large fixed solar array would cover one side of the structure with the inhabited modules attached to the opposite apex of the Delta. The side with the solar arrays would continuously face the Sun by rotating as the station revolved around the Earth. The configuration provided a planar structure for rigidity and attach area.

The Delta configuration's positive attributes included structural stiffness, a large enclosed service area, a large area to attach scientific payloads, no element differential motion, and uniform thermal conditions. Its negative ones included the following: 1) reduced earth viewing at points in the station's orbit; 2) multiple Remote Manipulator Systems would be required to do servicing and other tasks, because a track system to move a servicer would not be feasible; 3) the mass imbalance of the Delta station would have to be nulled by several magnetic torquers; and 4) simultaneous Earth and celestial viewing would be difficult.

Figure 9
CONFIGURATION CONCEPT OPTIONS

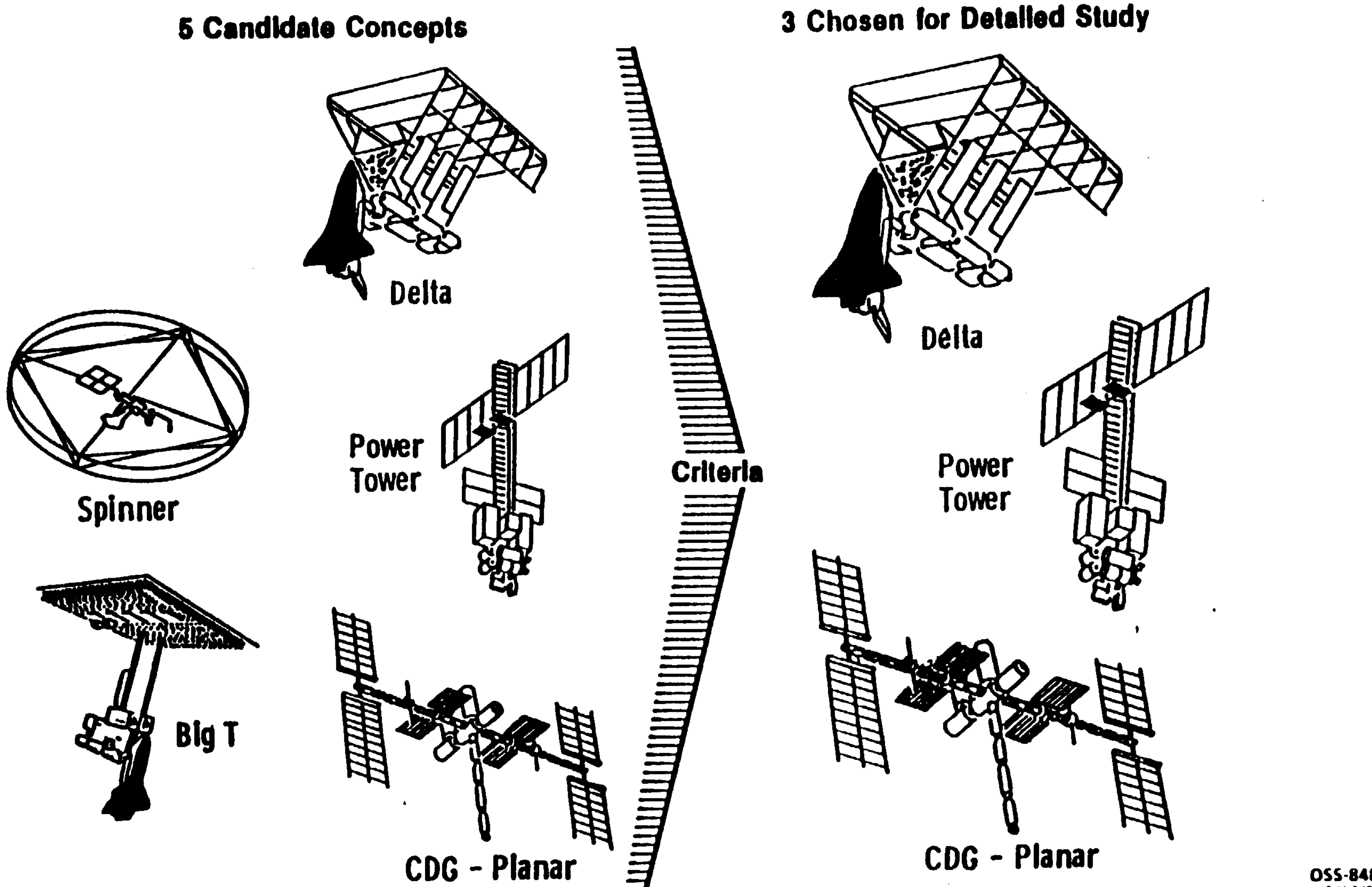

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Figure 10
DUAL KEEL CONFIGURATION

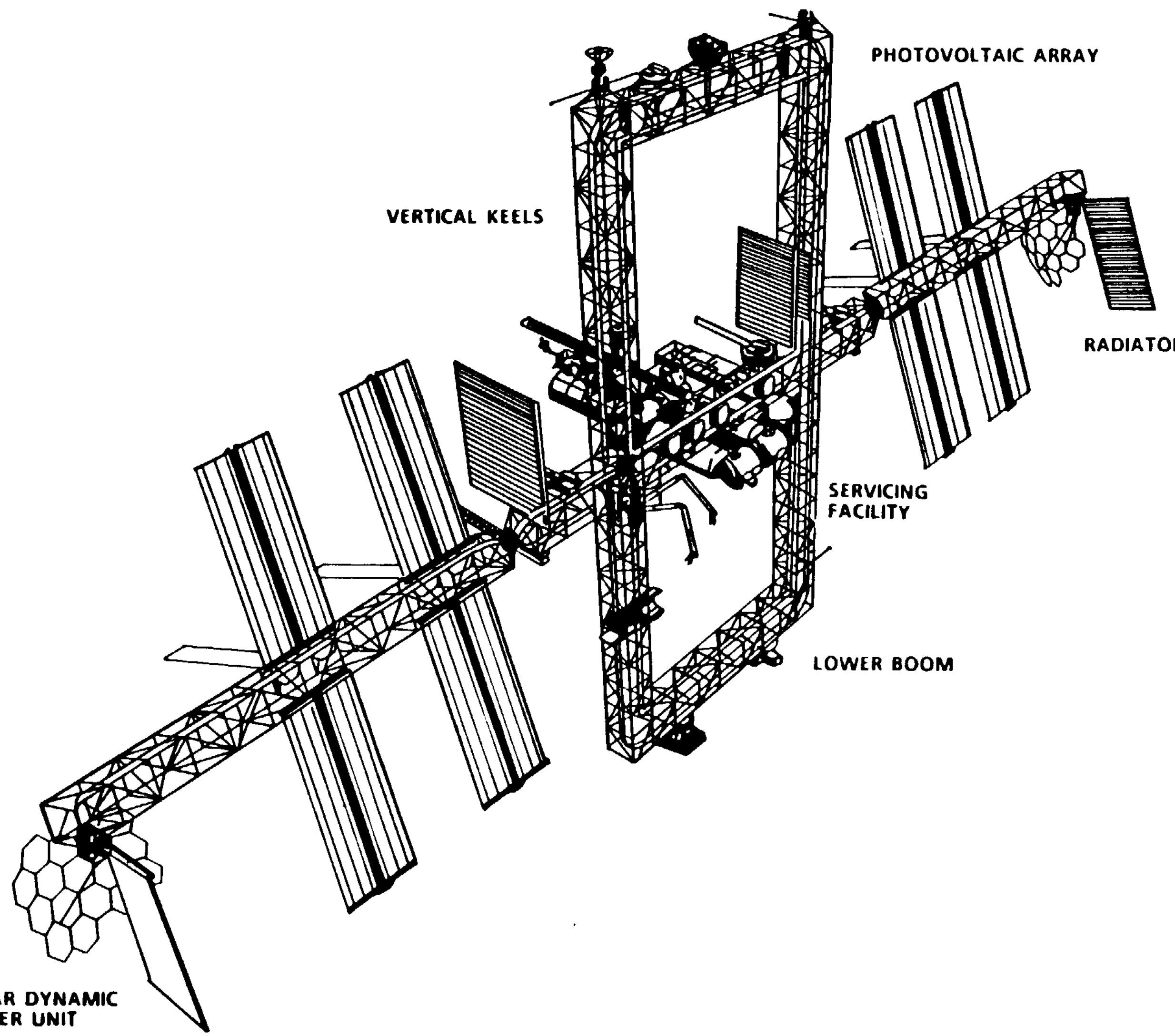

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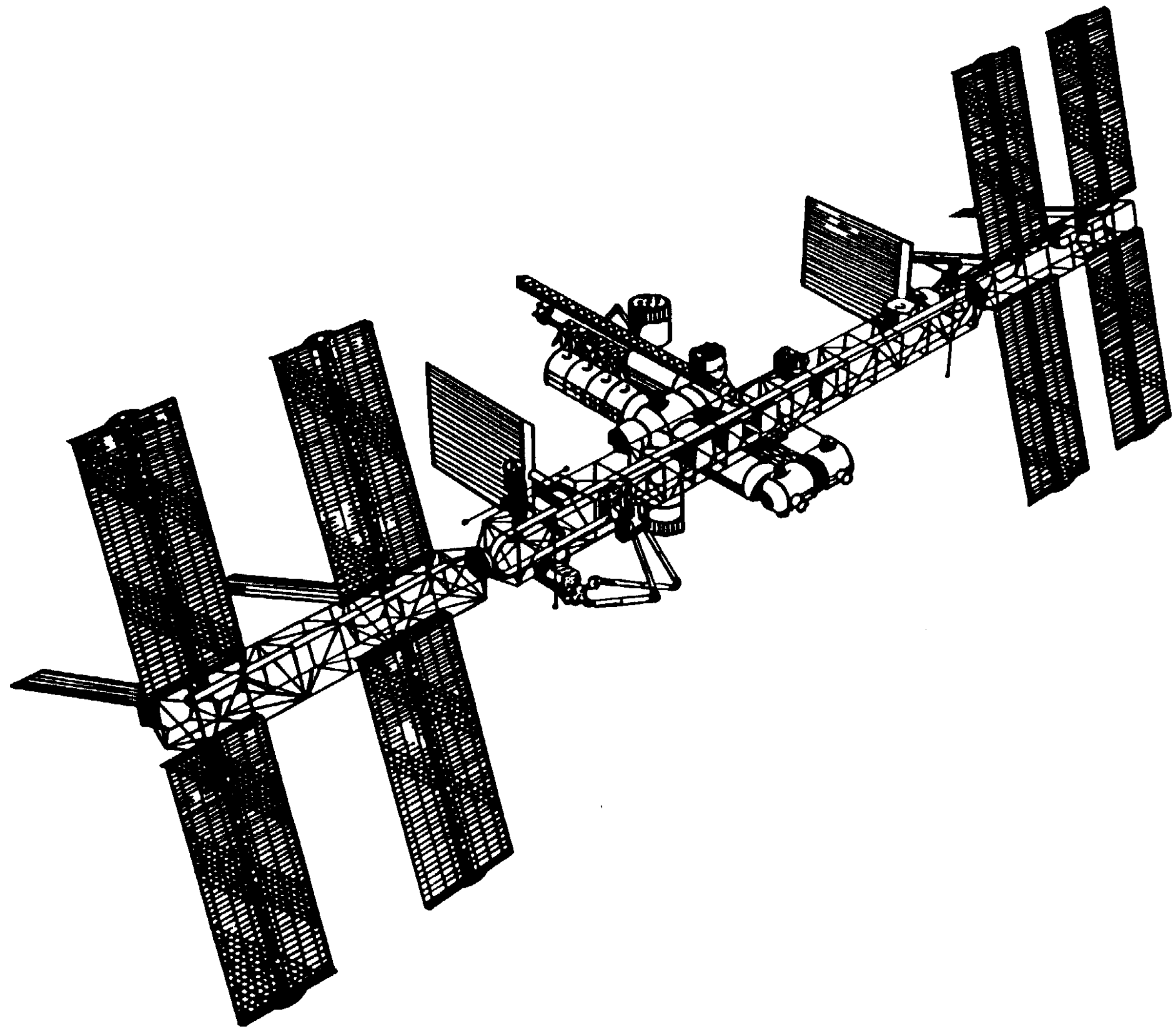
Figure 11
BASELINE CONFIGURATION



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Concept Development Group (CDG) - Planar - This configuration is an inertially stabilized modular design in which pressurized modules would be attached to a transverse structural boom. Power would be supplied by four gimbaled solar arrays. The planar configuration's positive points include having the power and other resources centralized, good orientation and viewing versatility, and relatively easy tether accommodation. Its disadvantages included the following: first, growth would be constrained by requiring symmetry. Second, the Station's solar arrays cannot be pointed continuously toward the sun because of the inertial flight mode of the Station. Third, the position of the solar arrays constrain construction, access, and some viewing. Fourth, special provisions would have to be made to scar the station for future power growth.

Power Tower - This configuration has a single vertical keel, with solar arrays mounted at one end, and the modules mounted to a boom at the other end, closest to the Earth. This arrangement makes it gravity gradient stabilized. Below the modules would be an area to attach Earth-observing instrumentation. The "tower" would rise above the boom to provide a location for celestial-looking instruments. This station is Earth-fixed, or oriented toward the Earth.

The Power Tower has a number of advantages. Its inherent stability makes it forgiving of mass imbalances, so future growth would be simple to accommodate. It could be fairly easily assembled in space. Of the three configurations considered in Phase B, the Power Tower configuration clearly best met the requirement for simultaneous, multidirectional viewing capability. Because of the Power Tower's orientation, communications are also easier to accomplish than they would be with other configurations. This orientation also makes proximity operations relatively easy. Finally, tethers can easily be used with this configuration, it would need less antennas and a simpler system than would the Delta or Planar configurations. The disadvantages are: 1) a potential limit on solar array size; and 2) special modifications would have to be made to scar the station for future power growth.

Of the three configurations analyzed in Phase B, the Power Tower was preferred although all three were considered feasible. All three configurations can be assembled with the Orbiter and a Station Remote Manipulator System. All three could accommodate either solar dynamic or solar photovoltaic power systems. The development costs of the three were considered to be essentially identical. The configurations differ somewhat in dynamics, operations, simplicity of thermal systems, and communications and tracking. For example, dynamically, the Delta requires more control moment gyroscopes (CMG) for stabilization than either the Planar or Power Tower.

Dual Keel - The Dual Keel configuration evolved from the Power Tower concept. The Dual Keel featured a a transverse boom with two parallel keels (see Figure 10). Pressurized modules would be located in the center of the boom. The upper keel would have attach points for celestial-viewing instrumentation; the lower keel would have similar provisions for Earth observation. In addition to the pressurized modules, there would be a servicing facility. The station would be powered by both photovoltaic and solar dynamic power generators.

The Dual Keel has several key advantages. These include its balanced microgravity environment, its extensive observation capability, and its adaptability for future evolution. Structurally, the Dual Keel design materially increased the torsional stiffness of the Station, compared to the Power Tower design, and simplified the necessary guidance and control system. The Dual Keel configuration could also provide housing for an Orbital Maneuvering Vehicle, and later, an Orbiting Transfer Vehicle. It can easily support a space assembly capability.

The main disadvantages of the Dual Keel were the number of flights and amount of EVA time that would be required for assembly.

In addition to these configurations, NASA also presented several that were representative of space-station modeling and conceptualization which has taken place since Wernher von Braun's studies in the 1950s.

Manned Orbiting Research Laboratory (MORL), 1966 version - This version of the MORL was designed to use the Apollo logistics system. The Saturn V expendable launch vehicle (ELV) was to be used for delivery to orbit and the Apollo Command Module for resupply. The MORL was to contain a two-man centrifuge in the center of the module for gravity conditioning and biomedical experiments. In addition, the configuration contained a "hangar" to be used as a staging area, supply site, laboratory, and a safe haven.

MORL Brayton Cycle Power System - This configuration incorporated the Brayton Cycle power system. The system was designed to produce 11 kW of power. This design also included an extended skirt to provide the increased radiator area required by the power system.

Large Space Station Concept - This configuration, designed in 1967, was proposed as a post-Apollo and Skylab space Station. The station was envisioned as a large-scale facility supporting a crew of 75 to 100. Artificial gravity would be provided (1-g) by spinning the station at 3.5 rpm. This station was designed to be 33 feet in diameter, and carried by the Saturn V ELV.

Phase B Modular Space Station - This configuration, was developed in the early 1970s after a decision was made to develop the Space Shuttle. The modules were to be 14 feet in diameter, and were to be delivered by the Shuttle.

Space Operations Center (SOC) - This was a joint effort by Boeing Aerospace Co. and Johnson Space Center. This design was also modular and Shuttle serviced. The SOC was to be a low-Earth satellite primarily designed for space-based construction and servicing. Intended for evolutionary growth, the crew size for this configuration was to increase from 4 to 20.

The NRC looked at one other configuration, The Harwood Space Station Concept Proposal. This concept was not presented by NASA.

The Harwood Concept - This configuration was made up of equal length elements configured into a large tetrahedral truss. Each member was approximately 57 feet in length (the maximum allowable length in the Shuttle bay) with pressurized modules interspersed with the structured elements. The concept had the advantage of being able to grow to any desired size. It had several major disadvantages, however. The elements were too long to be assembled by the Shuttle. The concept also showed no plan for integrating power systems and thermal radiators into the configuration, and if they were added, would require relocation at each stage of growth. The configuration did not support payload mounting and pointing requirements. Finally, contrary to Harwood's claims, there was no evidence that this configuration would cost less than the NASA baseline.